PROGRESS REPORT

of the

SOIL AND WATER CONSERVATION RESEARCH DIVISION

AGRICULTURAL RESEARCH SERVICE

This progress report includes a summary of the current research of the Division and a preliminary report of progress made during the preceding year. It is primarily a tool for use of scientists and administrators in program coordination, development and evaluation; and for use of advisory committees in program review and development of recommendations for future research programs.

The summaries of progress on USDA and cooperative research include some tentative results that have not been tested sufficiently to justify general release. Such findings, when adequately confirmed, will be released promptly through established channels. Because of this, the report is not intended for publication and should not be referred to in literature citations. Copies are distributed only to members of Department staff, advisory committee members and others having a special interest in the development of public agricultural research programs.

This report also includes a list of publications reporting results of USDA and cooperative research issued between April 1, 1967, and March 31, 1968. Current agricultural research findings are also published in the monthly USDA publication, Agricultural Research. This progress report was compiled in the Soil and Water Conservation Research Division, Agricultural Research Service, U.S. Department of Agriculture, Beltsville, Maryland.

UNITED STATES DEPARTMENT OF AGRICULTURE

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INTRODUCTION

The Soil and Water Conservation Research Division is charged with the responsibility of developing soil and water management practices that enable maximum utilization of these natural resources over indefinite time for the greatest good of all people. The knowledge so derived is put into practice by action agencies such as the Soil Conservation Service and the Bureau of Reclamation, by agricultural industries and by individual farm and ranch operators. The information gained is of paramount importance to Watershed Associations, River Basin Commissions and similar resource-using organizations, and to county and municipal governments.

Since resource problems are naturally related to the prevailing resources found in a region, the research program is organized around land resource units and geographic problem areas, with numerous field research units and regional research centers, and with a limited number of National Laboratories with a subject-matter-oriented charge.

SELECTED EXAMPLES OF ACCOMPLISHMENT

1. Contamination of Ground Water Under Cattle Feedyards Can Be Controlled. (RPA 901)

Laboratory studies at Fort Collins, Colorado, showed that there is a rapid die-off of the coliform population in feedlot soils at the usual animal stocking rates and the concomitant high ammonia concentrations arising from the urea excreted in the urine. The relatively short half-life of the coliform populations excreted in the feces, together with the failure to find any appreciable downward movement of the coliforms in the soil profile, indicate little danger of ground water contamination with coliforms of feedlot origin. Ammonia concentrations found in about half the total number of commercial feedlots examined were of the order of 1,000 p.p.m., a level shown to be strongly bactericidal to the nitrifying bacteria. The nitrification studies completed strongly suggest that feedlot stocking rates and corral management practices can be controlled to inhibit nitrification in feedlots and thereby reduce nitrate enrichment of ground water. Evidence indicates that energy-rich organic materials in animal excreta are leached into and through the soil profile under feedlots, thereby causing greater growth of the indigenous soil bacteria in the deeper profile and in the ground water.

2. Ground-Water Pollution from Nitrogen Low in the Imperial Valley. (RPA 901)

The possibility of polluting the ground water in the Imperial Valley by the large use of nitrogen has been of public concern for sometime. As a result of this concern, a nitrogen efficiency study was initiated at Brawley,

California. Results show that nitrate concentrations were high near the soil surface but dropped to zero at depths approaching the water table. These decreases were correlated with redox potential readings, indicating that the nitrates were reduced to nitrogen gas and lost into the atmosphere before reaching the tile lines. Water samples taken from the tile lines showed low concentrations of nitrates indicating that loss by denitrification can be sufficient in clay soils to prevent pollution of ground or drainage waters. Only 1.5 percent of 150 pounds per acre of nitrogen applied as fertilizer was recovered from the water. These findings are extremely valuable in predicting the possible pollution of ground water from field applications of nitrogen fertilizer.

3. Development of Management Systems for Star Grass Increases Beef Yield in Tropics by 40 Percent. (RPA 102)

Proper seedbed preparation, planting methods, and fertilization of star grass in Puerto Rico increased beef yields per acre by 40 percent. Star grass, produced in Puerto Rico for the first time, became established twice as fast as Pangola and appeared to be resistant to sugarcane aphids, and immune to stunt virus disease. Although the HCN content in star grass was higher than in other grasses, neither nitrogen rate nor drought increased the HCN content. Feeding trials will be continued to determine if HCN might be influenced by soil types and other soil and water management practices.

4. Early Stand Establishment by Deep Furrow Seeding of Winter Wheat is Potential Method for Erosion Control. (RPA 107)

Early stand establishment of fall-seeded wheat may be a potential method for erosion control on summer fallow, including the more humid regions of the Pacific Northwest. Recent improvements in equipment make seeding to moisture and rapid emergence possible on steep lands without depending on late fall rains to germinate the seed. Wheat seeded with a new version of the deep furrow drill during the second week of September emerged 7 to 10 days after seeding, and about 2 months earlier than wheat seeded at the same time with the conventional double disk drill. The early emerging wheat made substantial growth which provided considerable soil cover before the soil became cold. The late emerging wheat made little growth and provided essentially no soil protection because post emergence soil temperatures were unfavorable for rapid growth. The success and acceptance of early stand establishment depends on (1) maintaining sufficient soil water in the seed zone during the summer months when little or no rainfall is received, and (2) wheat production using wide-row spacing which is necessarily a feature of deep-furrow seeding.

5. Control of Selenium in Forage Affects Animal and Human Health. (RPA 102)

Livestock losses from white muscle disease have been estimated at over $10,000,000 annually in the Northwest alone. The disease is likely to occur where forages are deficient in selenium. Selenium is required in very small

amounts by animals, but is toxic if present in the diet in concentrations in excess of four parts per million. Research conducted over a 7-year period at the U.S. Plant, Soil, and Nutrition Laboratory has helped to clarify some of the biochemical processes involved in the movement of selenium from soils to plants to animals. Some implications important to environmental quality control are: (1) Areas in the United States where forage and feed crops contain different levels of selenium have been identified and shown on a United States map; (2) From this map, it is evident that interregional shipments of livestock feeds are a major factor in reducing selenium deficiency in the Northeastern States; (3) The addition of selenium to the soil is an effective, even though inefficient, method of prevention of selenium deficiency in animals; (4) The residual selenium left in the soil after cropping selenium-treated fields does not create a hazard of selenium toxicity; (5) Differences in selenium in the diets of residents of high- and low-selenium regions are reflected in the levels of selenium in the blood of these people, but there is no evidence of danger to humans in the United States from either selenium deficiency or toxicity. These findings will be of value to stockmen, feed companies, and Public Health officials in the evaluation of alternative methods of controlling selenium deficiencies in farm animals.

6. Cotton Gin Trash is Effective in Controlling Wind Erosion. (RPA 107)

Two major sources of air pollution (gin trash smog and soil dust) can be overcome by using gin trash for soil mulching instead of burning. Five tons per acre of cotton gin trash will reduce soil losses from wind erosion to a tolerable 4 tons per acre per year on loamy fine sandy soils. Research at Big Spring, Texas, to evaluate the effectiveness of this common practice of putting the trash back on the land for wind erosion control also showed that an application of 1 ton of trash would reduce erosion by 43 percent and 3 tons would cause a 69 percent reduction. Tillage with chisels or listers before application of the trash had some beneficial effect if done before applications of trash of less than 5 tons per acre. Tillage did not increase the effectiveness of the trash if more than 5 tons per acre was applied. Since the supply of cotton gin trash probably will not meet demands in most areas, it is recommended that the available material be used in the amounts specified to control erosion on the knoll tops and other highly susceptible spots on fields where erosion starts.

7. Light Limits Corn Yields. (RPA 102)

Yields of 377 bushels per acre were obtained at Urbana, Illinois, when corn was grown in a "light rich" environment created by large aluminum reflectors. Plants in the light rich environment had more tillers, more plants with two ears, shorter stalks with greater diameter, and a slightly larger leaf area than plants from inner rows or normal border rows. While aluminum reflectors are not commercially adaptable, these studies show that light is the limiting factor in corn production and that the present genetic yield potential is far from being reached. Improved light management, possibly through breeding

corn for smaller or more upright leaves to permit deeper light penetration into the corn canopy, is essential for maximum corn production.

8. Improved Design for Spillways. (RPA 107)

Hydraulic laboratory studies at Minneapolis, Minnesota, have produced elbows and transitions for high two-way drop inlet spillways that are free of destructive cavitation, simpler in shape, and easier to build. Such spillways are universally used on upstream watershed protection, flood prevention, and multiple-use reservoirs. Energy losses are low and so closely the same in all satisfactory shapes and combinations of the elbow and transition that considerations other than geometric shape, such as ease of construction or pressure distribution along the surfaces, will govern the selection of the shapes to be used. The elbow shape having the best hydraulic characteristics is an ellipse having a two-pipe-diameter major axis and a one-pipe-diameter minor axis.

9. Theory Aids in Understanding Plant Canopy Remote Sensing Imagery. (RPA 113)

The Kubelka-Munk (K-M) theory, a two-parameter representation of diffuse light transmission, has been applied successfully at Weslaco, Texas, to explain the reflectance and transmittance phenomena of stacked leaves. The procedures are sufficiently general to apply to an actual plant canopy. Virtually all mathematical relations used previously by agricultural scientists to specify light attenuation through a plant canopy are special cases of the K-M theory. The K-M theory has great flexibility to specify the interaction of light with a plant canopy. Many of the reflectance techniques applied to powder, paper, cloth, and other commercial products during the past half century can be adopted without modification to interpretation of reflectance from a plant canopy.

10. Aerial Contamination Contributes to Accumulation of Pesticides by Plants. (RPA 901)

Data from several field experiments suggest that aerial contamination frequently occurs when chlorinated hydrocarbons are applied. They determine the degree of contamination.

Greenhouse and field experiments were conducted at Beltsville in which corn was grown on Muskingum silt loam containing added amounts of dieldrin. The plants grown in the greenhouse were protected from aerial contamination, while no attempt was made to control this in the field. The corn was harvested at maturity and the dieldrin contents of the leaves, stalks, kernels, and cobs were determined. Only slight differences were found between the two experiments in the dieldrin contents of the stalks, kernels, and cobs. The leaves of the field-grown plants contained much higher concentration than those grown in the greenhouse. The leaf-to-stalk ratio of dieldrin concentrations in the field-grown plants was 50 times higher than that found

in the protected plants. This large difference is attributed to aerial contamination of the toliage.

11. Completely Automatic Surface Irrigation System is Here. (RPA 106)

Automation of surface irrigation systems continues to challenge researchers looking for ways to reduce labor requirements and at the same time conserve irrigation water by using more efficient application techniques. Remotely operated, hydraulically controlled butterfly gates installed in existing farm lateral turnout pipes, and powered with water pressure developed from a water wheel or domestic water system, have been successfully used to completely automate surface irrigated citrus groves in the Yuma Mesa, Arizona, and alfalfa-brome pasture near Fontenelle, Wyoming. Simplicity of operation makes the system attractive to prospective farm users. The irrigator or ditch rider need only open the headgate on the supply canal to irrigate from 10- to 100-acre blocks or more. More than one gate may be opened at a time to correspond to an irrigation set. When surface flow reaches a predetermined point down the irrigation run, a float-valve just outside the ditch is next irrigation set. When water commences to flow through the butterfly gates on the second irrigated set, a float-valve just outside the ditch is activated to close the gates on the first automated irrigation set. This sequence is repeated until the entire automated area is irrigated. The automated irrigation system described has been farmer-operated for one irrigation season. There have been few problems. Enthusiasm of citrus growers toward this development is encouraging and should hasten commercial application on a potential 17,000 acres in the immediate area in Arizona.

12. Soil and Plant Tissue Tests Aid in Producing Quality Idaho Potatoes. (RPA 102)

Experimental results in the Northwest show that available nitrogen in excess of the potato plant needs, whether from a residual or currently applied source, causes a proportion of the harvested tubers to be pointed, spindling, rough, and immature. The deterioration in quality caused by too much available nitrogen can be partially offset by excessive irrigation and by the addition of nitrogen in several increments during periods of maximum nitrogen uptake by the plants. Over-irrigation is avoided because it leaches nitrogen into the ground water. Adding nitrogen to the soil in small increments during the season in both furrow and sprinkler irrigation water appeared to offer good control at a minimum expenditure of labor. However, this method is not popular because a deficiency of nitrogen at a critical stage of growth can seriously reduce yields. After several years of study, soil and plant tissue tests have been developed at Twin Falls, Idaho, that enable the accurate application of nitrogen fertilizer for maximum production of high quality potatoes.

13. New management system increases forage and seed yields in the Northern Plains. (RPA 102)

A large potential for increasing production of forage and seed from dryland grasses has been shown on sloping land near Sidney, Montana, during the last four years. With the most favorable combinations of row spacings and fertilizer rates, green needlegrass, intermediate wheatgrass, and Russian wildrye produced 2400, 3200, and 3900 pounds of forage per acre, respectively. With the most favorable combinations of treatments, the same grasses produced 460, 350, and 440 pounds of seed per acre. These yields of forage and seed were about twofold greater than yields from nonfertilized grasses seeded in 60-inch rows. Contoured rows trap snow and rain. The nitrogen made it possible for the grasses to more efficiently utilize this additional water. The optimum row spacing for utilizing available supplies of water and fertility usually was different for seed and forage production and for each grass species. In contrast, western wheatgrass could not be maintained and grown in rows regardless of fertility level. These findings are important in developing management systems for livestock operations in the Northern Plains.

14. New method for designing water measuring flumes. (RPA 106)

At Phoenix, Arizona, a mathematical procedure has been developed to design highly accurate water metering flumes to fit a wide range of flow rates and channel conditions. The procedure eliminates the need for expensive flume calibration or conformance to standard dimensions. This has come about through a rigorous mathematical treatment of energy concepts that permits the successful theoretical prediction of calibration curves for critical depth flumes with a confirmed accuracy of $\pm$ 2 percent. Although the procedure is complex, it can be readily accomplished with computers at significant savings in time and money.

15. Functional equation enables more rapid determination of soil-erodibility measurements. (RPA 107)

An equation was derived that numerically relates the capacity of a soil to infiltrate rain and resist the erosive forces of rainfall and runoff to its physical and chemical properties. The equation has been successfully used to establish sediment loads from exposed urban construction areas. It enables computation of the Erodibility Factor (used in the Universal Erosion Equation) for hundreds of problem soils, thereby eliminating the need for expensive field testing and meeting an urgent need of many Soil and Water Conservation Districts. Tests have verified the equation's validity. This development at Lafayette, Indiana, will enhance the scientific design of measures to protect reservoirs and streams against pollution by soil from roadbanks, construction sites, and farm fields.

SEDIMENT YIELD AND DEPOSITION IN RELATION TO WATERSHED DEVELOPMENT AND PROTECTION

(RPA 107 - TECHNOLOGY OF WATERSHED CONSERVATION AND MANAGEMENT)

USDA and Cooperative Program

Location of Intramural Work	Scientist Man-years FY 1968
Vermont	0.7
Georgia	0.5
Mississippi	7.8
Missouri	2.1
Nebraska	0.2
South Dakota	0.6
Colorado	0.2
Oklahoma	1.0
Texas	0.4
Arizona	1.0
Total	14.5

Intramural program is supplemented by extramural support representing (a) 0.0 SMY's at State Agricultural Experiment Stations, (b) 0.0 SMY's at other U.S. institutions and (c) P.L. 480 funds in 0 countries representing 0 U.S. dollars equivalent.

Problems and Objectives

Sediment from soil erosion greatly complicates the development and use of water resources. About 1 million acre-feet of costly reservoir storage capacity are lost to sediment each year. Costly facilities and treatments are required to remove sediment from municipal and industrial water supplies. As a vehicle for transporting chemicals, sediment may contribute to eutrophication and other degradation of water quality; it hinders oxidation of organic pollutants in streams, damages fish and wildlife habitats, and diminishes recreation opportunities. Deposits of sediment in ditches and stream channels cause more frequent flooding and impair drainage of adjacent lands; they damage or enrich alluvial soils depending upon properties of the sediments and soils.

The objective of this research is to facilitate solution of sediment problems by providing:

1. Procedures for predicting rates and sources of sediment yield from watersheds.
2. Knowledge concerning rates and processes of reservoir silting and deposition of sediment in channels and on floodplains.
3. Influence of physiochemical properties of sediment upon sedimentation processes and aquatic environments.

Progress - USDA and Cooperative Programs

A. Sediment sources and yields

1. Sediment sources. Studies of runoff and sediment production from a 0.15 acre gully, from 5 to 15 feet deep, in Lafayette County, Mississippi, over a 3-year period revealed that the sediment concentration in the runoff waters was proportional to about the 3/4 power of the weighted rainfall intensities during runoff. The amount of sediment coming from the gully was essentially equal to the product of a constant, the amount of runoff, and the concentration. The 3/4 power of the weighted rain intensities during a runoff period served as an approximate measure of the combined erosivities of rain impact and surface runoff. The constant in the formula was thought to be an indicator of the erodibility of gullied surfaces. The value of the constant decreased during the study. Plausible reasons for a decrease in erodibility existed.

Instantaneous sampling of runoff from a bare, fallow surface during storm runoff events at the North Mississippi Branch Experiment Station, near Holly Springs, Mississippi, revealed that the soil concentrations in the runoff waters increased as the runoff rates increased; but the rate of increase differed from storm to storm. It was also found that sediment concentrations were much higher from plot surfaces rilled from previous storms than from surfaces recently reworked and leveled across slope. Both peak sediment concentrations and runoff rates occurred closely after

peak rainfall rates in the cases of rilled plot surfaces; but lagged several minutes in time when the plot surface had been recultivated and crosswise leveled.

Rill erosion on a 3.5-acre barren borrow area formed during construction of the Callahan Creek Reservoir, in central Missouri, produced 285 tons of sediment per acre during a 2-month period in May-June 1967. The total precipitation for this period was 10 inches which is about average, with the largest storm being approximately 2.5 inches in 12 hours. The slope of the area varied from 15 to 45 percent with the majority of it being about 20 percent. Only 2 months after the reservoir started collecting water, sediment from these 3.5 acres was found to occupy 1.0 acre-foot of storage in the reservoir. The severity of this rill erosion is apparent as one-sixth or 1,000 tons of the total sediment came from erosion on 1 percent of the total watershed area.

Studies are showing that gullies produce substantially less sediment than field erosion in the Iowa and Missouri Deep Loess Hills Land Resource region. Sediment yield from a 75-acre watershed farmed in contoured corn, near Treynor, Iowa, was 90 tons per acre in 1967. Erosion at a gully head in the watershed totaled more than 1,000 tons for the year but was less than one-sixth the amount of sediment derived from the watershed land surface.

One 6-inch rainstorm on the 75-acre watershed at Treynor, Iowa, produced 3 inches of runoff, runoff rates exceeding 75 c.f.s. for a 90-minute period, and eroded 380 tons of soil from the gully head. The sediment transport rate averaged 20 tons per minute during the first 6 to 8 minutes of this period, then leveled off at about 4 tons per minute for the next 30 minutes. During the first period, loose soil in the channel was removed while in the latter period sediment was eroded from the gully walls.

2. Roadside sources of sediment and control. A 9-year study of factors influencing sediment yields and their control from highway slopes in the Southern Piedmont, near Cartersville, Georgia, was terminated December 31, 1967. Some highlights of the findings were: about 12 of approximately 60 storms annually caused the bulk of the sediment production; one-third of the total sediment production for the year was usually caused by the largest annual single storm; bare roadbanks facing northwest produced twice as much sediment as roadbanks facing southeast, because of greater frost and freezing actions; most sediment production occurred during winter months, when soil moisture was high; on the average, 1 inch of rainfall produced 3.5 tons per acre of sediment; and average runoff from the roadbanks was 11.5 percent of annual rainfall.

The average sediment yield from two bare roadbanks during 1967 was 100.85 tons per acre, near Cartersville, Georgia. In contrast, the average yield from four nearby banks stabilized with vegetation was 0.48 ton per acre. This is a ratio of over 200 to 1 in favor of the vegetation

for stabilizing a critical sediment source area. This compares to a similar ratio of 24 to 1 that occurred during 1966. Again, type of cover was not a significant factor in preventing erosion; nor did the slope of the vegetated banks have a measurable effect on sediment yield.

3. Sediment yields. Suspended sediment concentrations measured in the Sleepers River Watershed, near Danville, Vermont, were generally low and there appears to be no correlation of concentration with size of watershed. Low suspended sediment concentrations may be due to the limitations of the measuring instrument which cannot measure coarse material. Sediment sources were generally near the stream and include streambanks, and roadcuts. The greatest amount of sediment was moved during the spring thaw by snowmelt runoff working in conjunction with frost action. Large storms and ice push moved bedload material weighing at least 50 pounds.

The effect of drought on sediment yields from rangelands near Newell, South Dakota, is illustrated by resurveys of two small reservoirs that had been previously surveyed in 1957 and 1962. The sediment yields in tons per acre per year for the period 1957-1962 were 5.1 and 0.35 as compared to 1.34 and 0.06 during the period 1962-1967. Precipitation was normal or above normal during the first period but drought conditions prevailed during the second period. These two watersheds are included in a group of 52 small reservoir watersheds being studied in this investigation.

Sediment yield from a conservation farmed watershed in the Texas Blackland Prairie at Riesel, Texas, was one-seventh the sediment yield from a nonconservation farmed watershed. A factor analysis to relate sediment yields to watershed characteristics and climatic factors showed that the important variables are volume of runoff, peak discharge rate, total rainfall, rainfall intensity, watershed area, cultivated area, and unterraced cropland.

At Chickasha, Oklahoma, the sediment yield of the Winter Creek watershed (33.3 square miles drainage area) since the construction of detention reservoirs in the basin has dropped to one-tenth of what it would have been if the reservoirs were not in the watershed. This is the second consecutive year this decrease has been observed. However, this year was also below normal rainfall.

B. Rates and processes of reservoir silting

In a cooperative study of reservoir trap efficiencies with the Soil Conservation Service and United States Geological Survey, the USDA Sedimentation Laboratory, Oxford, Mississippi, makes periodic sedimentation surveys of selected reservoirs located throughout the United States. Three were resurveyed and the sediment quantities in these and others were computed during 1967. Generally, sediment deposits have been lower than expected. Data accumulated from 12 of the 17

reservoirs under intensive study showed annual storage depletion rates of less than one percent, with two exceptions, for periods ranging from 4 to 12 years. Sediment accumulation rates ranged from 0.26 to 3.84 acre feet per square mile per year.

Three reservoirs in central Missouri were selected by the North Central Watershed Research Center, Columbia, Missouri, for trap efficiency studies. Instrumentation is being installed on these reservoirs to measure sediment inflow and sediment discharge and to record water temperature throughout each reservoir. Water temperature data will be studied to indicate movement of density currents. Sediment inflow will be measured by use of an automatic pumping sampler and stage recorder on the main stem above each reservoir. Preliminary sampling of all tributaries indicates that a high percentage of the sediment entering each reservoir will pass the sites where their sampling stations have been installed.

C. Stream and valley sedimentation

In parts of the Brown Loam hills section of north central Mississippi, valley sediment "plugs", formed at stream channel occlusions, have persisted for more than 30 years of record. Such persistence is due, at least in part, to underlying tough silts which resist headward incision of new or deepened channels below the "plugs". These circumstances are largely responsible for deposition of most sediment in headwater parts of creek valleys, so that concentrations of suspended sediment carried farther downstream are much lower otherwise.

Aggradation occurred in the gully channel below a level-terrace corn watershed in the Iowa and Missouri Deep Loess Hills, Treynor, Iowa, concurrently with degradation in the gully of an unterraced corn watershed. Over 1,000 tons of soil were removed from the latter gully. Under these severe testing conditions, when precipitation exceeded average by 6 to 10 inches and with 20 inches of rain in a 31-day period from May 28 to June 27, level terraces effectively stopped gully erosion in 1967. Testing of the effect of level terracing on gully growth is being continued.

D. Properties of sediments

A resampling in 1967 of the streambed materials of Cypress Creek and the Wolf River in west Tennessee once again confirms the fact of heavy pesticides contamination. Sampling was done by the USDA Sedimentation Laboratory, Oxford, Mississippi, and the chemical analyses by the USDA Pesticide Monitoring Laboratory, Gulfport, Mississippi, in a cooperative effort. Improvements in analysis techniques have resulted in the detection of chemical pollutants of streambed materials not found by these Laboratories in previous studies of the Lower Mississippi River and its tributaries, and in the detection of all at lower levels of concentration.

Publications - USDA and Cooperative Program

Sediment sources and yields

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Carter, C. E. and Parsons, D. A. 1967. Field tests on the Coshocton-type wheel runoff sampler. Amer. Soc. Agr. Engin. Trans. 10(1):133-135.

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MORPHOLOGY OF AND SEDIMENT TRANSPORT IN STREAM CHANNEL SYSTEMS IN UPSTREAM WATERSHEDS

(RPA 107 - TECHNOLOGY OF WATERSHED CONSERVATION AND MANAGEMENT)

USDA and Cooperative Program

Location of Intramural Work	Scientist Man-years FY 1968
Pennsylvania	0.5
New York	0.0
Mississippi	2.2
Colorado	0.0
Nebraska	0.5
Oklahoma	1.0
California	0.0
New Mexico	0.5
Total	4.7

Intramural program is supplemented by extramural support representing (a) 0.0 SMY's at State Agricultural Experiment Station, (b) 0.3 SMY's at other U.S. institutions and (c) P.L. 480 funds in one country representing $36,169 U.S. dollars equivalent.

Problems and Objectives

There are over 1-1/2 million miles of stream channels in the United States with drainage areas ranging from about 2 to 1,000 square miles. Streambank erosion and sometimes channel aggradation and degradation are serious problems requiring correction on perhaps 300,000 miles of these channels. To a large degree their stability is determined by the interactions of streamflow, materials comprising the channel bed and banks, and the amounts of sediment transported and deposited as bedload. Some of the channel erosion and degradation problems result from imbalance of sediment load in streamflow following erosion control or other works in tributary watersheds, some result from natural causes, and some result from trial and error attempts at stream channel improvements without proper provisions for the processes and forces involved in the natural morphology of stream channel systems.

The objective of this research is to facilitate correction of stream channel problems by providing:

1. Equations for calculating sediment transport and deposition in natural and artificial channels.
2. Criteria for identifying and quantifying the fluvial processes dominating the equilibrium or imbalance of stream channel reaches.

Progress - USDA and Cooperative Programs

A. Mechanics of sediment entrainment, transportation, and deposition

Turbulence over sand beds of various roughness was measured with constant temperature hot film anemometers in a 20-foot tilting hydraulic flume at the State University of New York at Buffalo, New York. Preliminary data indicate that accurate and reproducible turbulence measurements can be obtained with the constant-temperature anemometer. The measurements made indicate the roughness of the boundary increases the level of turbulence in free-surface flows as much as 5 percent near the boundaries.

In studies of the diffusion of sediment in a nonuniform flow it was found, in a 24-foot long flume at the State University of New York at Buffalo, New York, that the vertical mass diffusion coefficient for each of 3 different sediments varied with depth and longitudinal distance. The diffusion coefficients depended upon the relative roughness of the bed and were a function of the Froude number. It was also found that mixing in flows over wavy mobile beds at large relative dune roughness was more uniform with depth than indicated by the classical parabolic distribution usually accepted.

In a study of bedload transport the following bedload formulas are being programmed for an IBM 360 system using FORTRAN IV and including a sub-

routing for graphing the numerical output: Einstein, Modified Einstein, Kalinske, Meyer-Peter-Haywood, Yalin, Bagnold, Schoklitsch, Einstein-Brown, Sraub-DuBoys, Haywood, Casey, U.S. Waterways Experiment Station, Wilson and Meyer-Peter-Muller. Quantities of bedload transport, using data from actual cases encountered by USDA field offices, will be calculated with each formula and the results compared with the range of experimental data from which the formulas were derived. Primary aims are to identify conditions under which existing bedload transport equations give comparable results and the aspects of bedload transport needing additional research. This work is being accomplished under a research contract with Pennsylvania State University.

At the USDA Sedimentation Laboratory, Oxford, Mississippi, examinations of suspended sediment concentration profiles from several rivers and laboratory flumes show that the idea of a suspended sediment boundary layer can be introduced as a useful concept. The relative concentration equation within this boundary layer (adjacent to the bed) is in the form of an equilateral hyperbola, indicating that the sediment transfer coefficient in this region varies linearly with distance from the bed. Outside the suspended sediment boundary layer, the relative concentration function is exponential in form, as would be the case if the sediment transfer coefficient were constant in this region.

An error or Gaussian distribution function has been developed, at the USDA Sedimentation Laboratory, as an approximation to the vertical suspended sediment distribution in open channel flow. This mathematical model has been found to be equally as reliable as the classical equation in predicting the concentration distribution and has the advantage that its integral over the flow depth converges to a reasonable approximation of the total bed material transport rate per unit of channel width.

An instrument was designed, fabricated, and field tested to sample the coarse sediment moving along the bed during streamflows on Walnut Gulch, near Tombstone, Arizona. The instrument consists of a 1-inch-wide by 12-inch-high open metal slot intake which traverses the downstream edge of the V-floor at the overfall of a critical-depth flume. Sampling frequency and the rate of traverse across the stream are optional variables which are regulated by the design. The size distribution of samples collected with the sampler compare with the size distribution of the bed materials in the area of the flume. This indicates that the sampler is collecting a sample that adequately represents the coarse sediment passing through the flume. The data collected also appear to indicate that bed discharge is more or less independent of water discharge. The bedload discharge, which was observed to occur much later than peak water discharge, may represent the successive building and decay of dunes on the bed. The size of the sediment particles collected by the sampler diminished during the flow recession and may be related to water discharge.

B. Stream channel morphology

The following key points about erodibility of soils and streambank materials were established through studies at the USDA Sedimentation Laboratory, Oxford, Mississippi: (1) Water entry into cohesive materials produces mechanical forces, or relieves cohesive forces, which may result in surface particle detachment. In other words, erosion rates increase for a given erosive situation when water enters the channel boundary material; (2) the magnitudes of the internal detaching forces increase with increasing rates of water entry; and (3) for a given rate of water entry and flow erosiveness, the erosion rate decreases with decreasing bulk density.

An exploratory study on the formation of alternate bars in alluvial channels was carried out in a 20 x 100 x 3 ft. model basin at the Colorado State University, Foothills Campus, Fort Collins, Colorado. Preliminary analyses of the data indicate that the meander length is a linear function of the channel width and is also related to the width-to-depth ratio.

A newly dredged channel for Sugar Creek near Chickasha, Oklahoma, widened during April flows and released tremendous quantities of sediment. A transport rate of 722,000 tons per day was observed on April 12 at the gaging station. Sediment was deposited to a depth of 7 feet near the mouth of the newly dredged channel. In the Washita River, below its confluence with Sugar Creek, deposition occurred for about 6 miles downstream and up to 4 feet in depth. The banks of the river in this reach suddenly began to erode though prior to the deposition they had been relatively stable.

The streambeds in the monitored reach of Owl Rock Canyon, a tributary of Calleguas Creek Watershed, near Camarillo, California, continued to aggrade in every reach except those sections immediately below drop structures. The sand accumulation in the bed of this reach has widened the bottom of the bed, thereby decreasing the depth of flow of storm runoff and accelerating the rate of aggradation. A prolific new sediment source was discovered above the study reach and helps to explain the aggradation during the past year of high runoff when degradation might have been expected.

The size characteristics of sediments in the bed of Alamogordo Creek channel, near Santa Rosa, New Mexico, were found to vary with depth from a well-sorted to a very poorly-sorted distribution. Segregation of these bed materials appears to be related to depths of scour occuring during flood-flows. The coarse layers which are deposited early on a runoff recession agree with the scour depths measured by ropes established in the channel for this purpose.

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EFFECTS OF CLIMATE, SOILS AND VEGETATION ON THE HYDROLOGIC PERFORMANCE OF AGRICULTURAL AND ASSOCIATED WATERSHED LANDS

(RPA-107 - TECHNOLOGY OF WATERSHED CONSERVATION AND MANAGEMENT)

USDA and Cooperative Program

Location of Intramural Work	Scientist Man-years FY 1968
Vermont	1.9
Pennsylvania	1.5
Maryland (Beltsville)	2.8
Georgia	1.0
Florida	0.0
Ohio	1.7
Missouri	1.5
Oklahoma	2.0
Texas	0.6
Idaho	2.8
Arizona	3.5
New Mexico	0.0
California	0.0
Total	19.3

Intramural program is supplemented by extramural support representing (a) 0.5 SMY's at State Agricultural Experiment Stations, (b) 0.0 SMY's at other U.S. institutions and (c) P.L. 480 funds in 0 countries representing 0 U.S. dollars equivalent.

Problems and Objectives

The average annual water budget (precipitation) for the conterminous United States is 4.75 billion acre-feet, most of which falls on agricultural and associated rangelands. The kind and conditions of vegetative cover, soil characteristics, slope, cropping patterns, and conservation practices exert the first influence as to whether this precipitation becomes surface runoff, rapid subsurface flow, deep percolation, or soil moisture for evapotranspiration. The magnitude of this impact is largely speculative for many soil-cover complexes, but must be known in specific guantitative terms for optimal use of water and related land resources of watersheds and river basins. Specific values for the spatial variation of rainfall, snow deposits and evapotranspiration, including their probabilities of occurrence are also required for balancing the water budget on agricultural watersheds.

The objective of this research is to enable hydrologic predictions and forecasts for agricultural watersheds and river basins by providing:

1. Patterns of precipitation and climatic factors in agricultural watersheds.
2. The role of soils, vegetation, and land management practices as modifiers of the hydrologic cycle on agricultural watersheds.

Progress - USDA and Cooperative Programs

A. Precipitation patterns

1. Precipitation amounts

An analysis of 6 years of daily precipitation data from a network of 23 raingages on Sleepers River Watershed near Danville, Vermont, was nearly completed to: (1) determine the accuracy with which individual gages estimate precipitation at other points and over various areas; and (2) find the rate of deterioration of gage representativeness with distance, azmuth, and elevation change. No relationship has been found between correlation gradient and elevation difference, indicating that topography is not the principle controlling factor in shaping the field of correlation. Initial analyses of gradients show no relationship with azmuth or elevation difference. In designing a precipitation network, in this region, topography may not be as critical a factor as direction of storm travel or moisture flux, and a simple equal-area grid may not be the best configuration.

A network of 41 digital recording precipitation gages on the 162-square mile Mahantango Creek watershed near Klingerstown, Pennsylvania, indicates from 37 to 44 inches of annual precipitation. Most of the agricultural areas receive totals in the range of 38 to 42 inches. Precipitation amounts roughly follow the elevation contour lines with increasing precipitation as elevation increases. Orientation of the ridges and valleys to major storm

paths and larger topographic features appear to exert a greater influence on precipitation amounts than simple elevation differences.

Examination of rainfall data, by the USDA Hydrograph Laboratory, Beltsville, Maryland, to determine the prolonged persistence of wet and dry spells (drought) has revealed that long dry spells occur relatively frequently in the subhumid eastern United States and that their frequency distributions can be adequately defined by using the geometric distribution for the common frequencies and the Fisher-Tippett I distribution for extremely rare frequencies. It has been determined that a measure of the quality of raingage networks for hydrologic investigations required information on the mean of the field, the associated variance and the spatial autocorrelation. The shape of the depth-area curves for individual storms does not appear to be significantly influenced by season, storm duration and rainfall magnitude.

The network of 52-digital, punch-type, 5-minute recording precipitation gages installed on the 145-square-mile Little River Experimental Watershed, near Tifton, Georgia, became operational in January 1967. These gages are equipped with accurate electronic timers that punch out rainfall amounts almost simultaneously, thus yielding a series of 5-minute synoptic pictures of rainfall patterns over the entire watershed and adjacent area. During the early months of raingage operation, several functional problems were encountered, causing a skip in the record for a few gages. Most of the problems have been eliminated, and enough gages were operating during the year to give adequate measurements for the watershed.

At Chickasha, Oklahoma, rainfall was below normal for the sixth consecutive year, the lifetime of the study of the Washita River Basin to determind the effects of the upstream flood control measures. Any conclusions reached to date in this study must take this rainfall deficiency into account. The average rainfall for 1967 for the 1130 square-mile study area was 26.41 inches. The minimum amount of rainfall recorded was 21.23 inches and the maximum, 33.23 inches. These two stations were but 39 miles apart. Knowledge of spatial variability of rainfall is needed to improve estimates of total precipitation input to a watershed.

On the Blacklands Experimental Watershed, Riesel, Texas, annual point rainfall in 1967 ranged from 29.61 to 42.09 inches over a 7 square-mile area, the largest difference observed in 30 years of data collection at this location.

A unique method for calculating actual precipitation from ordinary measurements obtained from a dual arrangement of one shielded and one unshielded precipitation gage has been developed at the Northwest Watershed Research Center, Boise, Idaho. A direct relationship was found between the ratio of shielded catch to actual catch and the ratio of the difference in shielded and unshielded catch to shielded catch. The relationship is essentially independent of gage height, windspeed, and form of precipitation. The initial calibration curve developed shows that the percentage of true catch

by a shielded gage ranges from about 80 percent at a windspeed of 5 m.p.h. to about 30 percent for a wind of 25 m.p.h. Such a procedure for calculating actual precipitation offers a practical solution to the 2000-year search for a method to obtain reasonably accurate measurements of precipitation, particularly that of snowfall.

A recording system for surface measurement of total precipitation, snowmelt rates, and snow-water equivalents has been developed at the Northwest Watershed Research Center, Boise, Idaho. It consists of three major components; (1) A hydraulic weighing platform, (2) a measuring catchment for collection of water from the platform, and (3) a dual-pen pressure-recording system for recording the water equivalent of snow on the platform and the water collected in the catchment. The advantages of the system are: (1) It is completely mechanical; (2) it is relatively inexpensive considering its total performance; and (3) it gives complete information on snow accumulation, snowmelt, rainfall or any combination of these. This recording system satisfies the longstanding need for complete and accurate measurements of water reaching the earth's surface as required in hydrologic research and for water yield and flood forecasting.

An analysis of the correlation of rainfall catch between gages with distance has been made at the Northwest Watershed Research Center, Boise, Idaho, for 38 selected gages located in the 90-square-mile Reynolds Creek Experimental Watershed. The coefficient of determination for rainstorm amounts was found to decrease from 0.95 for a gage density of 1 per square mile to 0.92 for a gage density of 1 per 2 square miles. A linear relationship between the correlation coefficient of catch and distance between gages indicated an "optimum" gage network as one with gages one-fourth mile apart.

A major runoff-producing thunderstorm occurred on Walnut Gulch Experimental Watershed, Tombstone, Arizona, on September 10, 1967. The storm was centered on the upper central portion of the watershed and lasted for slightly over an hour. The maximum rainfall for the storm was 3.4 inches in 45 minutes. This was the largest point rainfall depth that has been measured in one hour or less for the period of record on Walnut Gulch (1956-1967). Depths of over 2 inches in less than an hour were recorded at 8 other raingages, representing an area of approximately 5-1/2 square miles.

Five convective storms were observed in the vicinity of Tehachapi, California during the 1966-67 water year. The intensities of the September 2, 1967, convective storm were higher, with the exception of the 5 minute value, than have been previously observed (during 5 years of study) for periods of up to an hour. The intensities (inches per hour) ranged from 4.08 for the 5 minute interval, to 3.28 for 30 minutes, to 1.91 for 60 minutes. This high intensity cell of about a mile radius centered in the valley portion of the 48 square-mile study area. This was the same area in which a storm of similar intensities centered on August 7, 1963.

An automatic twin probe gamma density gage for continuously profiling a snowpack was developed on Sleepers River Experimental Watershed, Danville, Vermont. The instrument enables investigators to accurately measure all density changes within the snowpack and correlate them with changes of energy flux. The development is in support of a continuing cooperative study of snow hydrology with the United States Weather Bureau.

2. Rainfall depth-area relationships

Rainfall depth-area relationships for single severe local storms, developed from a 1,500 square-mile network of 1,700 gages, operated at Coshocton, Ohio, were found to deviate materially from those based on published values from the national network of widely-spaced gages. The published design value currently in use for 100-year point rainfall is 2.6 inches with an average depth over 20 square miles of 2.3 inches. On the research network, the maximum point rainfall depth in one storm was over 4.8 inches, or twice the published value. The average depth for 20 square miles was 2.6 inches or over 10 percent greater than currently use value. Another storm had the same depth of 2.6 inches for 20 square miles, but with a 3.2-inch depth at its center. Average depth for a 200 square-mile area was 1.1 inches. These new and more exact data are needed in the safe and economic design of hydraulic structures.

Depth-area curves for the storm of September 10, 1967, were computed for the total depth of rainfall and the maximum 20-minute depth of rainfall at each station on Walnut Gulch Watershed. For comparison, similar curves were developed for the storm of July 22, 1964. This earlier storm occurred in the same general area and produced the same volume of runoff at Flume 6 although the peak discharges were different. Only the August 17, 1957, storm had higher peak discharges on the main stem of Walnut Gulch than these two storms during the 12 years of record and because the precipitation and runoff networks were not complete, analyses are difficult to make. For both the 1964 and 1967 storms, the 20-minute maximum depths exceeded 1.0 inch over more than 10 square miles of the watershed. The 20-minute depths were greater on July 22 than on September 10, but the total rainfall was far greater on September 10 than on July 22. Because of the longer storm duration on September 10, both events produced the same volume of runoff from Subwatershed 6 (430 acre-feet), but the peak discharge of July 22 was larger than that of September 10 (7340 cfs and 5010 cfs, respectively).

B. Soil moisture accretion and depletion

1. Infiltration and interflow

Intense instrumentation of a hillslope for the purpose of measuring subsurface flow towards a stream channel has been completed and 1.5 years of record obtained, at Sleepers River Experimental Watershed, Danville, Vermont. The study area consists of an isolated hillside with a slope of approximately 50 percent and a watershed area of approximately 1/2 acre.

The hillside consists of three sections with different latitudinal profiles; concave, convex, and straight. From each of these sections overland flow, interflow from a soil horizon at about 2 feet depth, and groundwater or phreatic zone flow from about 8 feet depth are isolated by means of tile drains and continuously measured. The three sections of hillslope thus measured produced overland flow 7.7 percent of the time; "interflow" from the soil horizon 16.1 percent of the time; and flow from the phreatic zone 100 percent of the time. The concave section of the slope produced a large portion of the total runoff from the study area, and the peak outflow rates in gallons per minute for this section are as follows: overland flow 42.07; "interflow" at soil horizon 5.69; phreatic zone 2.39. The straight section of slope was the lowest producer with corresponding data as follows: overland 4.0; soil horizon 9.13; phreatic 1.12. Further information is needed for analyses of these data, and sprinkler irrigation equipment will be used during the early summer of 1968.

Two prototypes of a transducerized recording tensiometer were constructed and tested by the Northeast Watershed Research Center, University Park, Pennsylvania, for use in studying unsaturated soil moisture contribution to streamflow. Information obtained to date indicates that the principle problem will be that of relating integrated quantities such as runoff with point measurements of soil moisture content and pressure. This problem is complicated by the high stone content and spacial variabilities of the soil.

The degree of saturation in the soil above the claypan profoundly influenced the rate of interflow on an 85-foot test plot of claypan Mexico silt loam, studied by the North Central Watershed Research Center, Columbia, Missouri. There was no interflow at the outlet of the plot until the water level at the center of the plot length was raised to 8-inch depth above the claypan. At lesser depths all water starting out as interflow at the upper end of the plot disappeared into the claypan. With an 8-inch water depth at the plot mid point, interflow persisted throughout the plot length and at the outlet it was 4.75 cm/day and hydraulic conductivity (k) 158 cm/day. At the 12-inch depth these values were more than doubled. Apparently interflow becomes an important phase of the watershed flow system only after the A horizon approaches saturation.

2. Soil moisture balance

Infrared aerial photographs of Little River Watershed near Tifton, Georgia, were made in December 1966, May 1967, and August 1967, as part of a Research Contract with the University of Georgia. Vegetation types and land use features were found to be distinguishable by color and tonal variation on the photos. A comparison of soil moisture samples and color variations of the infrared photos indicate such pictures have some, but limited, value for interpreting soil moisture. Soil moisture measurements with neutron probes indicate that differences in soil characteristics affect soil moisture depletion rates more than crop differences. This reduces the number of possible ecosystems (soil-cover combinations) that have to be considered in evaluating water yields.

A soils map of the Little River Experimental Watershed, near Tifton, Georgia, has been completed. Soil profile descriptions for a survey of hydrologic capacities of typical soils were prepared from pit studies on 44 sites. From these, 2,999 soil samples were collected and laboratory analyses made to determine texture, moisture-tension relations, bulk density, and hydraulic conductivity. Analyses of the surface soils on the watershed show the predominate soil type--Tifton series--contains sufficient concretionary material to provide erosion protection by "armor plating" the land surface. In the upper profile of Tifton soils, more than 22 percent of the textural fraction is larger than 2 mm. in size.

Soil moisture data from a unit-source watershed, with continuous corn and no-tillage, on well-drained silt loam at the North Appalachian Experimental Watershed, Coshocton, Ohio, showed that a mulch of corn stover and manure reduced evaporation loss and maintained moisture in the 7-inch plow depth at near field capacity from early May to mid July whereas moisture under conventional-tillage corn depleted to near wilting point. Storm rainfall absorbed by the topsoil of the mulch area developed a moisture content greater than its holding capacity and excess water then passed on down to the 27-inch depth. In the conventional-tillage area, evaporation from the exposed soil surface developed a water holding deficit in the top 15 inches of depth sufficient to retain all of the storm water infiltration.

Soil moisture versus volume relationships for deep loess of Monona silt loam, Treynor, Iowa, and claypan of Mexico silt loam, McCredie, Missouri, were found to differ widely, through analyses made by the North Central Watershed Research Center, Columbia, Missouri. Within 60 days after alfalfa kill on the loess soil, thickness of the 9-foot profile increased only 0.30 percent, while moisture content increased from 15 to 30 percent. Claypan moisture increase in 6 months was less than 3 percent while the layer thickness increased 0.35 percent. Coefficient of linear extensibility (COLE) values for the loess varied between 0.1 and 0.01. Those for the claypan were about 0.003. Soil survey data recently obtained by the USDA Hydrograph Laboratory, Beltsville, Maryland, for ARS-SWC experimental watersheds provide a means of obtaining similar COLE values for a large number and wide variety of soils over the country. This permits evaluating soil volume changes in relation to moisture and plant cover, which is important in the design of foundations and structures.

3. Soil-cover-treatment relations

Hydrologic response units within complex agricultural watersheds are now isolated in the USDA Hydrograph Laboratory hydrology model by grouping mapped soil units on the basis of soil depth and texture, elevation, aspect, slope gradient and slope position. Areas, average slopes, average lengths of overland flow, and average soil moisture storage capacities are determined for each response unit and used as parameters in watershed soil moisture balances for water yields and for computing rainfall excess to be routed through overland flows.

Annual runoff from the twelve two-acre watersheds at the Cottonwood Field Station in western South Dakota was heaviest from the heavily grazed watersheds. There was no significant difference between the runoff caused by rainfall from the moderately grazed watersheds and the lightly grased watersheds. Snowmelt runoff was greater from the lightly grazed watershed, possibly indicating that the standing vegetation holds more snow than is held on the heavily or moderately grazed watersheds.

Runoff and precipitation measurements were continued on 24 small watersheds on fine-textured soils and 30 small watersheds on coarse-textured soils near Newell, South Dakota. The mean runoff during 1967 for the coarse-textured watersheds was 0.924 inch and for the fine-textured watersheds it was 2.739 inches. Some analyses have been completed of five years of data from five "panspot" range sites and three "sandy" range sites. (Panspot sites are localized areas of low infiltration capacity and sparse vegetation that occur frequently on soils derived from Pierre Shales.) There are significantly more runoff events from the panspots and the runoff per event is significantly greater.

Runoff from 4 small (18 to 26 acres) grassland watersheds on a permeable, well-drained sandy loam site near Chickasha, Oklahoma, ranged from 0.10 to 0.44 inch for precipitation ranging from 30.29 inches to 32.05 inches. These watersheds were moderately to heavily grazed and had a total weight of vegetation in November ranging from 3617 to 4649 pounds per acre. Runoff from 4 other grassland watersheds on a clay loam site with poor internal drainage ranged from 1.16 to 1.23 inches for the two watersheds which previously had been cultivated. Precipitation on these watersheds ranged from 27.01 to 27.98 inches. Vegetation amounts on these clay loam watersheds ranged from 4961 to 5406 pounds per acre for the native grass and from 3140 to 3535 pounds per acre for the formerly cultivated area. In this case, soil characteristics appear perdominant in influence on runoff amount.

Runoff from two native grass watersheds in the Reddish Prairies, at Stillwater, Oklahoma, showed the overgrazed pasture to have twice the runoff of the adjacent, less heavily grazed watershed. Prior to the overgrazing of the one watershed, the runoff amounts had been approximately equal.

An increase in runoff following the start of grazing on a 20-acre bermudagrass watershed was observed at the Blacklands Experimental Watershed, Riesel, Texas. Compaction of the soil surface by grazing during a wet period is believed responsible for the increase. The opposite response was observed from one-fourth acre grass plots. Data show that two ungrazed plots had greater runoff than two grazed plots. More study is required before firm conclusions can be drawn on the effect of grazing on runoff.

Correlations of 1966 and 1967 runoff from twenty-four 6 by 12 feet plots with 5 descriptors of surface conditions by variables (roughness, percent cover, erosion pavement, soil cover, and crown cover), on Walnut Gulch

Experimental Watershed, Tombstone, Arizona, showed that crown cover and litter had the greatest effect in reducing onsite runoff. Roughness index (variance from a mean plane of 253 point measurements on the plot surface), negatively correlated with runoff, was not statistically significant in either year. Gravel was positively correlated with runoff and was statistically significant at the 0.01 level. Although rock alone was not correlated with runoff, when combined with gravel, it was found to be positively correlated with runoff at the 0.05 level. This was a reversal from the findings of 1966 when rock and gravel were negatively correlated with runoff. Crown cover was highly correlated (0.01 level) with a decrease in runoff. Although litter was negatively correlated with runoff both years, it was only in 1967 that it was statistically significant. Crown cover on the plots increased an average of 11.25 percent between 1966 and 1967. The absence of grazing and the large number of annual plants may explain this increase.

4. Watershed evapotranspiration

A study is underway at the Northeast Watershed Research Center, University Park, Pennsylvania, to test an equation developed by Kohler and Parmele for determining evapotranspiration at a point. The equation was tested with lysimeter data for the bare wet soil at Phoenix, Arizona, and for perennial rye grass at Davis, California. Using both empirical and log profile wind functions, the results presented verify that the relation is a suitable basis for estimating short-term potential evapotranspiration rates without the requirement for observation for net radiation over the surface of interest. In both cases moisture was not limiting. The heavy reliance of this method on incident radiation makes it a potentially suitable method for determining watershed evapotranspiration from a few point measurement of climatological data.

A test program to investigate the feasibility of a simple calorimeter for obtaining measurements of short- and all-wave radiation, and to develop instruments suitable for field use, was established on the Mahantango Creek Watershed, near Klingerstown, Pennsylvania. The shortwave sensing calorimeter, spectrally responsive to shortwave radiation (0.3 to 3.5 microns), was constructed and was ready for field testing. The change of temperature of water of any free solution in the calorimeter body will be used as the measure of radiation. An Eppley pyrheliometer will be used for the standard measure of shortwave radiation and a Schulze radiation balance meter and Beckman Whitley flat-plate radiometer will be the standards for all-wave radiation. The standard instruments have been checked out in the field with recording instruments and tests with the actual calorimeters will be conducted in the summer of 1968.

In studies at Fort Lauderdale, Florida, to develop concepts for differentiating between soil evaporation and plant transpiration within a watershed, linear relationships were found to exist between percentage of plant cover and annual evapotranspiration from Tifway bermudagrass when grown in evapo-

transpirometers on Arzell fine sand with 12-, 24-, and 36-inch water tables. On the light textured soils of the Southern Florida Flatwoods the ratio between evaporation from bare soil, a part-sod, and a full-sod is dependent on the depth of water table, as well as the amount and timing of the rainfall. Good correlation, r = 0.924, was found between USWB pan evaporation, E_p, and evapotranspiration, ET, from a full-sod for all three water tables during the 3-year test period. Correlation coefficients, however, between E_p and bare-soil evaporation were 0.795, 0.308 and 0.480, respectively, for the 12-, 24-, and 36-inch water table treatments. Low bare-soil evaporation rates during periods of low rainfall indicate capillary water movement to the surface from water tables 24 inches and deeper is very limited as compared to a 12-inch table. Contrariwise, with a 1-foot water table the surface soil stayed moist and soil evaporation was 110 percent of that from full-sod cover. This agrees with the energy-budget theory of evaporation, since the reflectance of insolation from plant foliage is greater than that from moist soil.

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GROUND-WATER RECHARGE IN RELATION TO USE AND MANAGEMENT OF AGRICULTURAL LANDS AND WATERSHEDS

USDA and Cooperative Program

Location of Intramural Work	Scientist Man-Years FY 1968		
	Research Problem Area		Total
	105	107	
Pennsylvania		1.5	1.5
Maryland (Beltsville)		1.2	1.2
Georgia		1.3	1.3
Florida		0.0	0.0
Ohio		1.2	1.2
Oklahoma		1.0	1.0
Texas	0.7	0.3	1.0
Idaho		1.3	1.3
Arizona	2.9	0.5	3.4
California	4.0	0.5	4.5
Total	7.6	8.8	16.4

Intramural program is supplemented by extramural support representing (a) 0.0 SMY's at State Agricultural Experiment Stations, (b) 0.0 SMY's at other U.S. institutions and (c) P.L. 480 funds in 0 countries representing 0 U.S. dollars equivalent.

Problems and Objectives

Nearly one-quarter of the water presently used in the United States for domestic, industrial and agricultural purposes comes from ground water. It is also the source of sustained base flow in most streams. Ground water supplies are adequate in some sections of the United States but serious overdrafts are occurring in other parts of the country. Aquifers are recharged naturally by water moving downward through soil profiles, from water absorbed into stream channel systems, and, artificially, by injection wells or other means. Aquifers are still described in qualitative or subjective terms rather than by specific quantitative measurements as needed; the rates of natural recharge and the interrelations of surface and ground waters are only poorly defined. New and improved methods for replenishing ground water by artificial means are needed.

The objective of this research is to facilitate and enhance the use and conservation of ground water resources by:

1. Defining ground water accretion, movement and basin recharge in relation to use and management of upstream watersheds.
2. Establishing aquifer-streamflow relationships for hydrologic systems analysis.
3. Developing principles, facilities, methods and economical systems for ground water recharge by artificial means.

Progress - USDA and Cooperative Program

RPA 105 - CONSERVATION AND EFFICIENT USE OF WATER FOR AGRICULTURE

A. Methods, practices and devices for ground water recharge

1. Recharge methods and facilities. Slowly permeable clay found on the surface of playa basins in the Southern High Plains prevents ground water recharge by deep percolation. A test was conducted at the USDA Southwestern Great Plains Research Center, Bushland, Texas, to determine if removing the clay layer would increase recharge rates through playa basin bottoms. The recharge rate (including evaporation) was only 0.06 inch per hour after removing the clay layer. Slowly permeable layers below 25 feet restricted recharge rate, thus making this method of recharge infeasible.

An alternate method of ground water recharge which would bypass the slowly permeable layers is recharge through shafts. Shafts 95 feet deep which terminate in dry sand of the Ogallala formation have been tested at Bushland, Texas. Last year it was reported that a small cavity mined in a shaft increased recharge capacity. Before modification, the shaft recharge capacity was 200 gpm, but after mining a small cavity it was 600 gpm. Additional mining during the past year increased the capacity of the shaft still further to 790 gpm. Shafts may be a suitable way to recharge relatively clear water.

2. Recharge site characterizations. A computational technique has been developed at the Water Conservation Laboratory, Phoenix, Arizona, for evaluating horizontal and vertical hydraulic conductivity of aquifers below ground water recharge installations. Field measurements required involve only the infiltration rate and piezometric pressure changes at two different depths in the aquifer. The method was confirmed with electrical analog studies. Horizontal and vertical conductivity at an experimental field site were found to be 388 and 24 ft./day, respectively, showing that the aquifer will permit high intake rates over large areas without excessive water table rise. This finding was confirmed with other field measurements. The method will be of considerable value in evaluating proposed ground water recharge sites.

A study in the San Joaquin Valley, California, demonstrated that the chemical properties of a subsurface soil layer must also be considered in addition to textural analysis in determining feasibility of the site for recharge.

Six permeability cells equipped with strain gages have been developed at Fresno, California, to study salt associated permeability changes of a confined highly compacted clay layer. The cells are mounted in a constant temperature ($\pm$ 0.2° C) air bath whose temperature is controlled by a separate constant temperature (but of wide temperature range) water bath. The strain gages of the cells are connected to a data acquisition system. The equipment has been designed with sufficient flexibility so that at a later time studies can be made using soil cores, or two soil columns up to 80 cm. in length can be put in the air bath.

At Fresno, California, a successful procedure for evaluating the zero shift of strain gage tensiometers has been developed. The injection of as little as 1 cc. of water into a donut-shaped chamber around the main tensiometer bulb causes the unit to fall to a precalibrated tension value which can be readout and compared to that of the previous experiment. Thus, by referencing tension-readout calibrations to the in-place calibration tension, field soil moisture tensions can be measured accurately over periods of many months.

At Fresno, California, a series of computer programs have been completed that summarize the work of R. E. Glover on the rise of ground water mounds under artificial recharge areas. This puts this theoretical analysis in a form that can easily and rapidly be applied by engineers working on field problems in ground water management.

Field comparisons in the San Joaquin Valley, California, of jetted well logs and the shallow seismic survey method indicate that the portable seismic timer is a fairly reliable tool for predicting the existence of possible profile restrictions to depths up to 50'. Hardpans are very accurately predicted because of their high density. Continuity of these hardpans is also accurately surveyed.

B. Quality of ground water

Nitrate concentrations indicate ground water pollution is occurring beneath the Fresno-Clovis (California) urban area. Nitrate sources, direction of movement, and areal distribution were determined by contouring ppm nitrate values from sampled wells. Resampling after 7 months showed no appreciable change in values, except where wells received direct recharge from irrigation ditches. Nitrate values from 30 to 40 ppm were common.

RPA 107 - TECHNOLOGY OF WATERSHED CONSERVATION AND MANAGEMENT

A. Ground water accretion, movement, and basin recharge

Pumping tests were run on 59 wells in the upper Mahantango Creek watershed, near Klingerstown, Pennsylvania. Reasonable values for storage and transmissibility coefficients were not obtained because of restrictive pumping periods but specific capacity data were used to evaluate the effect of various geologic variables on well yield. Wells in valley bottoms had higher yields than wells in upland or valley settings but were more variable. Wells in sandstone had the most consistent yield, followed by wells in shale and a siltstone-shale sequence. Wells in siltstone gave the most variable yield. Wells drilled into beds dipping from 30^{o} to 60^{o} were highly variable and generally higher yielding. Wells drilled into beds dipping from 60^{o} to 90^{o} were the least productive but the most consistent. Water elevation contour maps developed from the well data indicate that the surface topography watershed divides are coincident with the ground water divides.

Studies in the Ahoskie Creek Experimental Watershed at Ahoskie, North Carolina, show the basin is underlain, from the surface down, by the following strata: mixed silts, sands, and clays (Pleistocene); Yorktown formation (Upper Miocene); Beaufort formation (Paleocene); undefined formation (Upper Cretaceous); and Tuscaloosa formation (Upper Cretaceous). The Pleistocene material ranges from 20 to 40 feet, and the Yorktown formation from 25 to 65 feet in thickness. These beds all dip to the east. The Pleistocene beds contain interfingering permeable sand aquifers near the base, which are covered by more impermeable surface materials. Water levels in the Pleistocene aquifers seem to be directly related to free water table levels. The Yorktown formation contains a semi-confined aquifer that shows some response to rainfall recharge. The Beaufort formation and the Upper Cretaceous beds all dip to the southeast. All of these beds contain artesian aquifers that show little response to surface recharge. Indications are that seepage losses from the surface are probably minor above the Yorktown formation, and insignificant below the Yorktown. The experimental watershed appears to be, hydrologically, a closed basin.

Intensive surface and subsurface hydrology investigations are underway on a small, 72-acre, farm watershed near Tifton, Georgia. An impermeable clay that prevents deep seepage was found to underlay the entire surface phraetic aquifer, or soil zone. Ground water seepage moves laterally along the aquiclude and is collected by a surface storage pond at the lower end of the watershed. The boundary between the aquifer and aquiclude has been mapped by drilling and hypsometric curves prepared to show the location and distribution of potential ground water storage. Total volume of the aquifer storage is 725 acre-feet, and laboratory tests indicate the aquifer porosity is 30 percent, which gives a maximum subsurface storage of approximately 290 acre-feet. Specific yield is 18 percent as determined from the volume of water drained from pores in 15 hours. Preliminary vertical and horizontal hydraulic conductivities determined for the aquifer are 1.41 and 3.31 inches/hour, respectively. Computerized methods are being developed to obtain ground water budgets for the basin for time intervals of one hour or more by use of a flow network and the subject physical data.

A geological reconnaissance map of the Little River Experimental Watershed, Tifton, Georgia, was completed in 1967. Sinks were found in the watershed, but 26 percent of these occur in an area covered by Pleistocene eolian (windborne) sand that covers less than 3 percent of the total area. This appears to be an important finding. If further studies confirm a strong association between the sinks and eolian sand, a clearer understanding of the origin and development of "Grady ponds" should be forthcoming in relation to the geologic time scale. This information may also give a clue as to the time required to develop upper soil profiles in the Coastal Plain.

In Taylor Creek Experimental Watershed, which flows south into Florida's Lake Okeechobee, ground water well records show that closing canal control gates following floodflow, which usually occurs in September and October, would conserve an appreciable volume of ground water for use during the dry season that normally follows these floodflows. Also in Taylor Creek watershed, under normal ground water depths (3.00-3.75 feet), evapotranspiration during cooler months lowers water tables at a rate of about 0.15 inch per day. At the same depths, in the warmer months, the rate is about 0.45 inch per day--a threefold increase.

Observations of perched ground water table fluctuations beneath a sprinkled plot in unglaciated land of the North Appalachian Experimental Watershed, Coshocton, Ohio, showed the buildup of a temporary ground water mound, but it dispersed unexpectedly in an elliptical shape with its major axis at right angles to the plot land slope. This direction was found to coincide with that of the major joint system of rock fractures. This finding has an important bearing on the need to identify and quantify the geometry and hydraulic characteristics of rock fractures in relation to its influence on water yield and floods in the whole watershed flow system.

Storm water intake into soil beneath a level terrace in Missouri Valley Deep Loess, Treynor, Iowa, reached the water table 40 feet below in 2 days. Maximum recharge to soil moisture and ground water storage occurred 6 days after ponding water in the terrace channel. Water movement through the soil was essentially vertical. A localized recharge mound in the water table reached a maximum height of about 5 feet at the sixth day. Observations indicated that construction of level terraces when the soil is moist causes soil compaction in the terrace channel and a reduction of infiltration rates. This should be avoided to achieve maximum storm water intake. It was apparent that the capacity of soil water storage in deep loess is enormous and that structures such as level terraces will profoundly change runoff and soil water storage quantities in the flow system.

A map showing the depth of valley fill in the study reach of the Washita River Basin near Chickasha, Oklahoma is nearly complete. The survey indicates that the total volume of unconsolidated sediment is two cubic miles. The effective porosity is approximately 25 percent. Thus, there is about 0.50 cubic mile of ground water (1.7 million acre-feet) in storage in a valley distance of about 29 miles.

Ground water observations below flood detention reservoirs in Sugar Creek watershed near Chickasha, Oklahoma, show ground water levels to have increased at a rate of 0.1 ft./yr. to 0.3 ft./yr. since the dams were completed in 1964.

At Sonora, Texas, loss rates from flood detention reservoirs due mainly to leakage into cracks, fissures and solution caverns beneath the reservoirs are high and depend upon site characteristics. However, for any particular reservoir the stage of the water was the most significant factor controlling loss rate. Equations relating loss rate to reservoir stage were developed for five reservoirs in Lowery Draw in the Edwards Plateau. Water table fluctuations near a reservoir indicate that water lost from reservoir storage goes directly to ground water.

Penetration of rain water in the Lompoc Recharge Area (California) was unusually shallow during the 1966-67 water year even though precipitation was slightly above average (at Lompoc 13.45 vs. 13.04 inches). Penetration depth at six vegetated sites ranged from 5.5 to 15.5 feet. This shallow penetration was attributable to many small storms distributed over an unusually long rainy season. Deep translocation from precipitation of the 1966-67 water year occurred only at a denuded site. Unsaturated drainage through this profile of Marina sand has occurred during every water year since the vegetation was removed in 1957. Based on data of 10 years, deep translocation at this denuded site can be predicted as follows (in inches per water year):

Deep translocation = 0.845 (Precipitation - 4.15)

This means that about 84 percent of the precipitation in excess of 4.15 inches drains completely through this 20-foot profile.

The primary source of ground water recharge in most watersheds with ephemeral streams in the arid and semiarid southwestern United States is from transmission losses in the streambed. Soil moisture measurements on both the Walnut Gulch Experimental Watershed, Tombstone, Arizona, and on the Alamogordo Creek Experimental Watershed, Santa Rosa, New Mexico, have shown that there is no direct rainfall recharge of ground water. The penetration of soil moisture, as indicated by moisture blocks, generally was limited to the upper two feet of soil but has been found to penetrate to 4 feet in swales or beneath small sump areas. The ground water table in most areas of these watersheds is 100 feet or more below the land surface. Recharge does occur through the streambeds as has been shown by the well measurements in some portions of the Walnut Gulch watershed.

B. Aquifer-streamflow relationships

1. Subsurface contributions to streamflow. Water yields to streamflow from shallow aquifers can be computed with a mathematical model developed in the USDA Hydrograph Laboratory at Beltsville, Maryland. Storage-flow relationships, derived from hydrograph recessions, were segmented into a series of linear systems. On the premise that greater storage per unit flow indicates more devious paths, the indicated reservoirs are associated with successively deeper strata in the ground profile. Infiltrated water can thus be routed through a series or parallel set of indicated reservoirs to compute return flow to the stream. This model closely duplicated various conditions of surface and subsurface flows shown by hydrographs measured at the North Appalachian Experimental Watershed, Coshocton, Ohio.

Location investigations of streamgaging sites for Little River Experimental Watershed in the Southern Coastal Plains Land Resource Area near Tifton, Georgia, reveal subsurface flow is confined to the stream valley alluvium. Deep seepage losses will be small from channels. In the upper reaches of Little River, the impermeable aquiclude is a nonmarine, poorly sorted sand, interbedded with partly indurated sandy claystone and clay (Miocene series, Hawthorn formation, Ashburn member). In the middle reaches of the basin, the strata change facies to a calcareous sandy clay with some degraded limestone (Lower to Middle Miocene, Hawthorn formation), which continues through the lower reaches to the terminal gaging site. There is a wide range in the cross-sectional area of the stream valley alluvium, which will affect base flow rates. Solution cavities were found in the Hawthorn formation beneath both upland and stream valley areas. Their occurrence will undoubtedly have some effect on subsurface and surface hydrology.

Relative magnitude of underground water sources that contribute to streamflow in the North Appalachian region appear to be identifiable by water temperature. On the North Appalachian Experimental Watershed, Coshocton, Ohio, where aquifer storage is small temperature changes in seepage flow to streams and seepage flow rates varied widely but closely followed temperature changes in the soil. Temperature changes in seepage flow from aquifers of larger storage capacity were less responsive to soil temperature fluctuations.

2. Stream channel transmission losses. Ephemeral stream channels, such as Walnut Gulch, near Tombstone, Arizona, are very inefficient water conveyors. Transmission losses reduce most streamflows to mere trickles. On Walnut Gulch, only 10 to 15 percent of the precipitation generating runoff ever appears as surface runoff at the watershed outlet. Management of the stream channels offers one of the large unexplored potentials for increasing water supplies in semiarid areas. In most reaches of channel, much of the water absorbed by the channel alluvium is lost for beneficial use by man through high evaporation losses from the alluvium and through transpiration losses from riparian vegetation. In other reaches of channel, much of the water moves vertically to the regional water table. The disposition of the transmission loss water is a most important consideration in the evaluation of the water yield of the basin. Were the channel bed and banks between Flume 6 and the watershed outlet sealed, the surface water yield of Walnut Gulch could be increased by about 90 percent. Sealing just the lower 4 miles of channel between Flumes 2 and 1 would increase the surface water yield of Walnut Gulch by about 67 percent. The effect of such sealing on ground water recharge and on increasing the flood potential downstream still must be evaluated.

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RPA 105 - CONSERVATION AND EFFICIENT USE OF WATER FOR AGRICULTURE

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RPA 107 - TECHNOLOGY OF WATERSHED CONSERVATION AND MANAGEMENT

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HYDRAULICS OF CONSERVATION STRUCTURES AND CHANNELS

(RPA 107 - TECHNOLOGY OF WATERSHED CONSERVATION AND MANAGEMENT)

USDA and Cooperative Program

Location of Intramural Work	Scientist Man-years FY 1968
Maryland (Beltsville)	1.3
Vermont	0.5
Georgia	0.0
Mississippi	1.4
Minnesota	3.0
Oklahoma	4.0
Idaho	1.0
Arizona	1.0
Total	12.2

Intramural program is supplemented by extramural support representing (a) 0.5 SMY's at State Agricultural Experiment Stations, (b) 0.0 SMY's at other U.S. institutions and (c) P.L. 480 funds in 0 countries representing 0 U.S. dollars equivalent.

Problems and Objectives

Channels for water conveyance and structures for water control are essential features in programs for the conservation and development of land and water resources. Projecting past experience from 817 watershed work plans, developed under the Watershed Protection Act (PL-566), indicates a potential investment of some $20,000 million for structures and channel improvements that would be required in the remainder of the country needing such projects.

The objective of this research is to improve the performance, reduce the costs, and enhance the safety and appearance of water control structures and channels by providing:

1. New knowledge about hydrodynamics of water flow.
2. Hydraulic performance and discharge capacities of channels and structures.
3. Criteria for the hydraulic design of water control structures and means and measures for stream channel stabilization.

Progress - USDA and Cooperative Program

A. Hydrodynamics of surface water systems

A watershed surface runoff system can now be mathematically derived from the watershed topographic map through techniques developed in the USDA Hydrograph Laboratory, Beltsville, Maryland. Treating contour lines as equipotentials, stream lines are drawn normal to the contours, forming flow tubes. Each flow tube starts on the watershed boundary and continues down slope until it intersects a channel. Each flow tube is divided into curvilinear rectangles on which land use and treatment, soil type, and precipitation can be superimposed. For each flow tube, the input is developed as distributed precipitation excess. Overland flow is routed through each stream tube and is discharged into a channel as lateral inflow. Channel routing computations proceed down each natural channel. The utility of this surface runoff model is twofold. One, inputs can be modified according to soil, cultural practices, and land cover for each incremental area bounded by the contour lines crossing each stream tube. Second, the natural drainage patterns composed of the overland flow and channel flow system is retained in flow routing computations.

At Stillwater, Oklahoma, a re-analysis of all available data from tests on vegetation-lined channels to establish critical tractive force values (a measure of the ability of a channel liner to protect an earth channel from scour) for various vegetation-soil combinations showed that channel slope influenced the value. For example, for green bermudagrass linings on erosion resistant soils the critical tractive force in pounds per square foot is equal to $0.98 + 0.19\ S$, where S is the slope in percent. It was

also observed that the critical tractive force increases with age of the channel if the vegetation is well maintained.

Computation of Manning's n values from channel test data at Stillwater, Oklahoma showed that errors as large as 11 percent resulted when the velocity head coefficient was assumed to be 1.0 (the usual practice in channel computations) instead of the true value which was obtained from velocity distribution measurements.

At Stillwater, Oklahoma, the velocity head coefficient and the momentum coefficient were related to the ratio of depth of vegetation to hydraulic radius. For both nonuniform and spatially varied flows the relationships were similar. These relationships make it possible to estimate the values of the two coefficients from measurements of the vegetation depth in the channel. The significance of this development is that appreciable errors in the prediction of flow profiles in channels can result if the velocity head coefficient or the momentum coefficient is incorrectly estimated.

Information on channel resistance, essential for flood routing and flow predictions required for the design of water conveyance channels and streambank protection works, is being obtained at the Northwest Watershed Research Center, Boise, Idaho. Representative streambeds in the Reynolds Creek Experimental Watershed have been found to have the shape of a parabola. A linear relationship has been obtained for limited data between the ratio of discharge to the square root of channel slope and the square root of the ratio of the hydraulic radius to the friction factor times the cross-section area. A direct proportionality was obtained by incorporating a roughness parameter or roughness length on the channel bottom.

Additional information on floodwave travel in dry stream channels was obtained on Walnut Gulch Experimental Watershed, Tombstone, Arizona during a 5,000-c.f.s. peak discharge on September 10, 1967. The 14,740-foot reach of channel between Flumes 6 and 2 has a mean gradient of 0.88 percent. It is subdivided into 7 segments with 6 water level recorders located at approximately 2,000-foot intervals to provide a continuous water level record. The average velocity of the flow front moving over the dry streambed for the entire channel reach was observed to be 8.8 feet per second. Velocities of the hydrograph peak computed from the individual wave recorders varied from about 4 to over 18 feet per second. The average velocity of the peak for the entire reach was 14.4 feet per second. The Manning's "n" value computed using the average velocities, was 0.013 for the peak discharge and 0.021 for the flow front. These values are lower than what might be expected for such a channel, but the values are in general agreement with previous observations in the channel segment. These observed roughness values indicate that care must be used in selecting the Manning's "n" value for slope area determinations of peak discharges on such channels.

B. Criteria for hydraulic design of structures and channels

Comprehensive measurements of drag forces on streambed particles and observations of the mean forces that prevailed at incipient motion have been tabulated and published at the USDA Sedimentation Laboratory, Oxford, Mississippi. The data cover a wide range in liquid viscosities and bed particle densities. Computed lift forces that prevailed at insipient motion are to be checked in future laboratory measurements.

At Minneapolis, Minnesota, hydraulic model tests of the two-way drop inlet spillway showed that elbows having an elliptical shape or composed of circular segments will be as cavitation-free as an elbow shape based on the free streamline theory. This means that elbows which are easier to design and build perform as satisfactorily as complicated elbow shapes based on theoretical and analyses.

Analyses were made at Minneapolis, Minnesota, of tests by the Corps of Engineers on the Swarthmore elbow used by the Soil Conservation Service on high two-way drop inlet spillways. The data show two regions of adverse pressure gradient where the flow may separate from the elbow wall. There is also an area of negative pressures relative to the friction gradeline where cavitation may form. These findings suggest that the use of the complicated Swarthmore elbow and transition be discontinued.

From hydraulic laboratory tests at Minneapolis, Minnesota, two transitions having simple geometrical shapes have been developed for use between the two-way drop inlet spillway elbow and the barrel. These findings will permit the design of cavitation-free transitions for high drop inlets.

Trash racks for drop inlets were tested on a full size structure and on a scale model at the Outdoor Hydraulic Laboratory, Stillwater, Oklahoma. Sticks and logs (rigid trash) were introduced into the flow. Results from model and full size tests were in close agreement. Open type racks were found more subject to trash lodging than racks on inlets having a solid top deck or anti-vortex plate. Trash racks with side skirts show less loss of flow capacity due to trash accumulation than do racks without side skirts. The amount of trash that reached the drop inlet was greatly affected by wind patterns.

C. Flow measurement and water metering devices

Tainter gates were found to be feasible as flow measuring devices by model studies conducted at the Georgia Institute of Technology, Atlanta, Georgia, under a research contract. Best hydraulic performance is obtained when either all Tainter gates are closed (overflow only), or when all gates are opened partially with identical gate openings. In three-gated structures satisfactory results were obtained with only the center gate opened, but not with only the outer gates opened. Energy dissipators in the stilling basin did not function properly when large differences in

upstream and downstream water surface elevations existed along with low downstream stages. Variables found to bear importantly on the problem of using Tainter gates as flow measuring devices include (1) differences in headwater and tailwater elevations, (2) head on gate during overflow, (3) gate opening, and (4) length of gate, and (5) lower gate lip angles as measured from the vertical.

Model studies at the Outdoor Hydraulic Laboratory, Stillwater, Oklahoma, showed that a training wall constructed upstream from a flow measuring flume would control the thalweg, reduce low flow meandering, and improve the stability of the flume rating. The training wall affected the head-discharge relation in the low flow range and a new calibration was required.

An HS flume for temporary attachment to broad-crested V-notch weirs for low flow calibration of the weirs was developed at Chickasha, Oklahoma, and tested at Stillwater, Oklahoma. The attachment of the flume was found not to affect the head-discharge relationship for the V-notch weir. The slope of the V-notch did not affect the rating of the HS flume. Low flow calibrations of various broad-crested V-notch weirs of smooth concrete, steel, and sand grain coated steel showed that the nature of the crest did not affect the discharge coefficient.

The use of a fluormeter to measure the dilution of a fluorescent dye, Rhodamine WT, has proven very useful in measuring stream discharge and time-of-travel in studies at the Northwest Watershed Research Center, Boise, Idaho. Although a constant-dye-injection system is preferable in water measurement, the slug method has proved acceptable in steep, rough stream channels where complete mixing is accomplished. Fluorescence was found to decrease with increase in suspended sediment. Careful attention to details of procedure, calibration, and equipment operation has given results in water measurement accuracy comparable to current meter methods of discharge measurement.

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STREAMFLOW REGIMES AND QUALITY OF WATER AS INFLUENCED BY THE USE AND MANAGEMENT OF AGRICULTURAL LANDS AND UPSTREAM WATERSHEDS

(RPA 107 - TECHNOLOGY OF WATERSHED CONSERVATION AND MANAGEMENT)

USDA and Cooperative Program

Location of Intramural Work	Scientist Man-years FY 1968
Vermont	0.8
Pennsylvania	0.5
Maryland (Beltsville)	2.5
Virginia	1.0
Georgia	1.1
Florida	0.0
Missouri	1.6
Ohio	1.4
Wisconsin	0.3
Colorado	1.0
Montana	1.0
Nebraska	0.3
South Dakota	1.4
Oklahoma	1.7
Texas	0.6
Idaho	1.2
Arizona	2.0
New Mexico	0.5
Total	18.9

Intramural program is supplemented by extramural support representing (a) 0.0 SMY's at State Agricultural Experiment Stations, (b) 0.0 SMY's at other U.S. institutions and (c) P.L. 480 funds in 0 countries representing 0 U.S. dollars equivalent.

Problems and Objectives

The effects upon floods and water yields of land use and water management upstream is often a controversial and largely unanswered question. Present methods for predicting streamflow regimes are mainly based upon empirically derived relationships between precipitation and runoff or estimates of probability as indicated by past experiences. New prediction schemes based upon concepts of water accounting are a pressing need, particularly for predicting effects of watershed management upon water yields at downstream points. The prediction scheme or schemes must also be capable of providing, on ungaged watersheds, dependable, authoritative estimates of volumes, magnitudes and probabilities of single flood events, as required for economical design of spillways, channels and other engineering works for various water control purposes.

The objective of this research is to facilitate multiple use of water and related land resources on watersheds and river basins by providing:

1. Specific information on storm runoff, floodflows, and water yields from research watersheds.
2. Mathematical procedures for predicting streamflow regimes by synthesis of information about watershed geometry, precipitation, infiltration, evapotranspiration, geohydrology, dynamics of surface flow, and storage and release of water.

Progress - USDA and Cooperative Programs

A. Floodflows and storm runoff

A Fortran computer program was developed at Blacksburg, Virginia, to scan flow depth data obtained from the Fischer and Porter water level recorders and to select only those values needed to define the streamflow activity. Storm events during August 1967 produced a record peak discharge of 0.3916 inch per hour for the 1,068-acre Chestnut Branch watershed in Bedford County, Virginia. The maximum runoff volume for selected time intervals from 1 to 8 days which resulted from these August events were more than double the previous maximum values.

Four concrete V-notch weirs, along with stilling basins, recorder shelters, and footbridges, were constructed in upper Little River Experimental Watershed near Ashburn, Georgia. Weirs were built atop interlocking sheet-steel piling driven to impermeable material. Steel-piling wingwalls were used to force all flow over weirs. Three sites are each equipped with two digital-type stage recorders that register both upstream and downstream water-surface elevations. Only one recorder is required at the fourth site. Recorders were installed in December, with streamflow records officially beginning January 1, 1968. These stations complete the instrumentation needed for surface hydrology studies in the upper 20.5 square-mile watershed.

Mechanical performance of the gaging stations has been good. It will, however, be necessary to raise the weir-crest elevations approximately 6 inches on two of the three submerged weir stations to obtain better low-flow records.

Studies of storm runoff from gully watersheds in the Iowa and Missouri Deep Loess Hills, Treynor, Iowa, showed that maximum peak flow from unterraced corn watershed was 5 inches per hour and that from the level terraced corn watershed was only 0.3 inch per hour or a difference of over 90 percent. Storm runoff volume on the latter was 0.24 inch, or about 6 percent of the total rainfall of 3.88 inches, while that from the unterraced area was 3.6 inches, or about 62 percent of the storm total rainfall of 5.88 inches. Storm water retention for the maximum event was 3.3 inches in the terraced area and 1.01 inches in the unterraced--a very marked benefit from terraces. Under the severe test of a storm of probable recurrence of about 100 years, the level terrace system proved effective in water control.

A study of the regime of the Washita River mainstem flows during a ten-year period prior to the installation of flood control works was completed at Chickasha, Oklahoma. Available records of precipitation and streamflow were used to determine unit hydrographs for six tributaries and to develop the relationship between hydrograph characteristics and watershed characteristics. The unit hydrographs for the remaining 64 tributaries were then estimated on the basis of measurable watershed characteristics. Estimated tributary flows were routed to reproduce known hydrographs at river gaging stations. This study, in effect, calibrates the model of the Washita River basin and provides one basis for determining the changes wrought by flood control measures introduced into the basin.

A flood routing procedure was developed at Riesel, Texas, which employs variable time increments of variable storage coefficients. This new procedure provides more accurate predictions of hydrographs than to the conventional methods which employ constant time increments or single storage coefficients.

The storm of September 10, 1967, which was centered at Rain Gage 52 on the upper boundary of this mixed-grass brush watershed, a tributary within Walnut Gulch Experimental Watershed, Tombstone, Arizona, produced nearly 75 percent of the precipitation as runoff. A pond, with a capacity of 8.9 acre-feet, was almost empty prior to the inflow on September 10. With the estimated 10 acre-feet of water which passed over the spillway, the computed runoff amounted to 2.6 inches over the watershed. It was estimated, both from the spillway geometry and the pond capacity above spillway level, that the peak discharge was at least 200 cfs, or better than 1,500 cfs per square mile.

B. Water yield

Analysis of rainfall-runoff relationships for Sleepers River Experimental Watershed, Danville, Vermont, led to the development of an index for

predicting minimum flows based upon easily obtainable watershed parameters. These parameters are precipitation, soil drainage characteristics, watershed area, stream frequency, and drainage density.

It has been found, from studies at Fort Lauderdale, Florida, that annual runoff volumes can be predicted with reasonable accuracy for the Southern Florida Flatwoods by the equations:

(1) $Q = 0.94 (P - 35)$, when area is greater than 15 square miles
(2) $Q = 0.83 (P - 35)$, when area is less than 15 square miles

where Q equals expected runoff in inches, and P equals annual rainfall in inches. These predictions are based on rainfall exceeding 40 inches annually. The larger watersheds have contributed, on the average, almost 94 percent of the rainfall in excess of 35 inches to measured runoff; and the smaller watershed about 83 percent. When annual rainfall drops below 40 inches, runoff between 2 and 5 inches can be expected to occur. These small volumes are not predictable since they are dependent on spatial and temporal distribution of rainfall.

Studies of streamflow data from a gage, the location of which was dictated by topographic requirements, at the North Appalachian Experimental Watershed, Coshocton, Ohio, showed an abnormally low volume of sustained flow for a 75-acre watershed in unglaciated land. A supplementary gage located 220 feet downstream, but based on and tied into a natural impervious underclay gave substantially higher rates of sustained flow and an annual water yield volume 32 percent greater than that at the former gage whereas the drainage area increase was only 5 percent. However, stormflow values at the two sites were found to be essentially the same. These findings brought out the importance of considering the geologic situation in selecting the location of stream gages to evaluate water yield and the effect of land use and treatment thereon.

Water losses from ponds have been investigated at Newell, South Dakota. During a four-year period an untreated pond with surface dimensions of 50 x 50 ft. and a maximum depth of 11.5 ft. lost 84.2 percent of its total storage to evaporation and seepage. Another pond treated with bentonite but with a surface area four times as great lost 81.1 percent. A butyl-lined pond 50 x 50 x 11.5 ft. deep lost 35 percent of its water to evaporation during two years of measurement.

A combination of conservation land treatment and terraces at the Blacklands Experimental Watershed, Riesel, Texas, reduced annual runoff 23.6 percent below that from a conventional, nonconservation treated area. However, a terraced watershed with poor agronomic practices showed a runoff increase of 20.5 percent.

Water yield maps covering the State of Idaho, prepared at Moscow, Idaho, have been published. The 20 quadrangle maps, drawn at a scale of 1:250,000

but published at a scale of 1:200,000, were produced by distributing the measured water yield from large watersheds over the watershed area by adjusting for elevation and vegetation. These maps have been put to immediate use by State and Federal agencies in developing water inventories and water planning for Idaho.

The storm of September 10, 1967, was one of the 3 largest runoff producing storms at stations on the mainstem of Walnut Gulch, Tombstone, Arizona, for the period of record (1956-1967). This storm represented only about 15 percent of the summer precipitation but produced 75 to 85 percent of the runoff at stations on the main channel. As much runoff was measured at the outlet of the watershed from this storm as from all the storms together in 1965, 1966 and the remainder of 1967. Thus, besides being important for flood design purposes, these unusual storms are also extremely important in water yield analyses.

Runoff per unit area from an 84-acre drainage area (137 acre-feet per square mile) for the storm of September 10, 1967, was more than twice that measured on any other subwatershed of the Southwest Watershed Research Center during the period of record. Although a frequency estimate for this runoff event is difficult to make, a general idea can be conveyed. Runoff approaching 130 acre-feet per square mile for a 100-acre, or less, subwatershed may occur on some part of the Walnut Gulch Watershed on the order of once every 10 years, but on a specific small watershed, probably no more often than once in 100 years.

C. Physical characteristics of watersheds

Good progress was made in the hydrologic soil cover complex investigations for Little River Experimental Watershed at Tifton, Georgia. A drainage-net map showing all basin streams and their order is complete. Morphometric data such as stream lengths, bifurcation ratios, and length-width ratios have been determined for areas above proposed streamgaging stations. A hypsometric map has been constructed using 50-foot contour intervals, and hypsometric integrals have been computed for basins ranging from 2nd-order to the main 6th-order basin. Sample areas chosen randomly throughout the watershed indicate that 3rd-order basins are the smallest sample (grain size) representative of the geomorphic diversity of the area.

D. Watershed models

1. Digital models

The mathematical model of hydrologic performance developed by the USDA Hydrograph Laboratory, Beltsville, Maryland, was expanded to include return flow, thus completing a 4-step continuum of precipitation, infiltration, surface runoff, and subsurface return flows. The subsurface flow model was developed with ARS data from Coshocton, Ohio, and Hastings, Nebraska, watersheds and was test applied to Florida conditions using ARS data from Fort

Lauderdale. The level of sophistication will be improved by continued studies and alternatives will be developed in each of the four steps to meet situations of limited input information and various demands of output. Cooperative efforts were initiated between the USDA Hydrograph Laboratory and various ARS projects and their local cooperators to test apply this model by application to ARS records at Tucson, Arizona; Danville, Vermont; Coshocton, Ohio; Fennimore, Wisconsin; Blacksburg, Virginia; Hastings, Nebraska; and Fort Lauderdale, Florida. Cooperative efforts with the University of Ohio and with Virginia Polytechnic Institute also include applications of the Stanford model (as programmed in FORTRAN IV by the Weather Bureau) to ARS records at Coshocton and Blacksburg, respectively.

Mathematical models of surface runoff phenomena have been investigated at Fort Collins, Colorado. The characteristic equations for overland flow with lateral inflow on a converging surface have been solved using the kinematic wave approximation. General solutions are obtained by numerical methods. Analytical solutions have been obtained for the recession side of the hydrograph. Solutions were obtained in a dimensionless form with one parameter indicating the degree of convergence. The shape of the rising and falling hydrographs can be changed considerably by varying this parameter. A better fit to steeply rising hydrographs may be obtained by including a converging component in a mathematical watershed model.

2. Analog models

Progress was made at the Utah State University Water Research Laboratory in the development of the analog model for hydrologic phenomena. Development of this model is being pursued to explore the feasibility of using electronic analog and digital computer models as research tools for extending field data on Walnut Gulch Experimental Watershed, Tombstone, Arizona. A considerable effort has been expended in an attempt to develop a computer program to facilitate the input of precipitation data. Two concurrent methods are being pursued. The first method involves using the analog computer for plotting isohyetal lines within a watershed area. The computer uses a resistance paper in conjunction with an x - y plotter. The second method involves a digital computer program which incorporates a multiple coaxial correlation technique to correlate precipitation with elevation and slope. A parabolic equation is applied to approximate a smooth curve between points of equal precipitation, thus generating an isohyetal line which can be output on an incremental plotter. Testing of the model is continuing using actual field data to verify the assumptions associated with the model equations.

E. Hydrologic data releases

Compilation and editing of HYDROLOGIC DATA FOR EXPERIMENTAL AGRICULTURAL WATERSHEDS IN THE UNITED STATES, 1962, has been completed and scheduled for publication as USDA Miscellaneous Publication No. 1070. Satisfactory progress was made on the preparation of the 1963 data for publication. Editing of the 1964 data was well underway.

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THEORY AND PRACTICE FOR CONSERVATION AND MANAGEMENT
OF WATER SUPPLIES FOR AGRICULTURAL USE

(RPA 105. - CONSERVATION AND EFFICIENT USE OF WATER FOR AGRICULTURE)

USDA and Cooperative Program

Location of Intramural Work	Scientist Man-years FY 1968
Georgia	2.1
Ohio	0.5
Iowa	1.3
Colorado	1.4
Montana	1.0
Wyoming	0.7
Idaho	0.3
Nevada	3.6
Utah	2.3
Arizona	7.9
Minnesota	0.5
Total	21.6

Intramural program is supplemented by extramural support representing (a) 0 SMY's at State Agricultural Experiment Station, (b) 0 SMY's at other U.S. institutions and (c) P.L. 480 funds in 1 country representing 18,091 U.S. dollars equivalent.

Problems and Objectives

Annual water requirements for agriculture, primarily for livestock water on Western rangeland and supplemental irrigation in the humid area, are estimated to be 67 million acre-feet greater by the year 2000 than at present. The Soil Conservation Service is providing technical assistance for the construction of over 50,000 farm ponds per year. Water losses particularly to the irrigation farmer increase his production costs and lessens his competitive position with other water users. Seepage losses from conveyance and storage structures exceed 20 million acre-feet per year. Evaporation from small ponds and reservoirs in the Western water-short area exceed 3-1/2 million acre-feet annually. Uncontrolled evaporation from the soil is many times this amount. Western rangelands are frequently over or under grazed for lack of a strategically located livestock water supply. Criteria are lacking for location and development of the shallow ground water supplies and also for maximum utilization of the available farm water supply in many sections of the country.

Major objectives of the research are to provide technology for increasing the effective farm water supply by:

1. Developing principles, materials and methods to reduce seepage from conveyance and storage structure.
2. Developing principles, materials and methods to reduce evaporation from water and soil surface.
3. Developing design criteria for precipitation harvest catchment areas, storage structures and shallow ground water recovery facilities.
4. Developing systems for efficient utilization of the total farm water resource.
5. Reclaiming for reuse water wasted by uneconomic range vegetation.

Progress - USDA and Cooperative Programs

A. Seepage control

1. Water borne asphalt. At the U.S. Water Conservation Laboratory, Phoenix, Arizona, asphalt emulsions have been shown to be useful as water-borne sealants for reducing seepage losses from small reservoirs. Seepage reduction of 99 percent has been obtained in operational reservoirs by adding one gallon of emulsion per square yard of surface area to water in the reservoirs. Successful treatments should be obtained if the following requirements are met: (1) The emulsion must be highly stable and infinitely dilutable in water; (2) soils to be treated must be nonexpansive; (3) pre-treatment seepage rates should be greater than one foot per day; (4) weed growth in the pond must be prevented; (5) mechanical damage to the seal must be prevented; and (6) water should be maintained in the pond continuously. The longevity of the asphalt seal is currently under investigation.

2. Membranes. In an outdoor weathering program of canal liners conducted at Logan, Utah, elastomeric materials failed more rapidly when subjected to strain. Tests were made at 0, 25, 50, and 100 percent elongation.

Bonding tests indicate that the bond obtained between like and unlike membranes, such as plastic film and butyl sheeting, can vary widely with the bonding agent. This is also true of agents that bond these materials to concrete and steel.

The puncture resistance of vinyl was found to be inversely related to ultimate elongation and directly related to tear resistance and tensile strength.

3. Clay sealants. At Reno, Nevada, playa clay samples, 5/8-inch thick, treated with water of 600 ppm total salts and a SAR of 2.0 showed a seepage rate 25-fold higher (.61 ft. per day) than samples treated with water containing 150 or 300 ppm total salts (same SAR). Approximately 1.0-foot of water passed through the samples under a 5-foot head during the experiment. Seals of the same thickness of 12 percent montmorillonite and 88 percent sand mix remained tight during a month of laboratory testing. Even at the 600 ppm salt level the seepage was only .0065 ft. per day.

Buried blanket seals of montmorillonite continued to hold their seal very well at the Yerington, Nevada, study site. The seals were a 12 percent montmorillonite--88 percent sand mix placed as a 3-inch blanket and covered with 6 inches of sand. Five years after installation these seals lost water at the rate of 0.26 feet per day (drop in reservoir water surface) compared to loss from the untreated controls of 2.08 feet per day. During the 5 years the seals were subjected to extensive drying as well as trampling with a horse to puncture the seal. It appears from the success of the seal that the 6-inch cover thickness is adequate to resist drying, and combination of the cover and seal appear to be thick enough to resist punctures from trampling. A seal such as this can actually have a self-healing effect. This was demonstrated by seepage measurements which showed that seepage first increased then decreased, following trampling.

Recent work with playa sediments in Nevada has shown them to be excellent sealers. These playa sediments are old lake bottom clays that are impervious to water. Such sediments have the advantage of being loaded and placed as a seal with relative ease since they do not require crushing to form a smooth, dense seal. The cost of loading and transporting a playa sediment 9 miles to the experimental reservoirs at Fallon, Nevada, was $0.153 per square yard of 2-inch seal. Cost of hand placing was $0.06 per square yard. The cost of this seal in place (before covering) is comparable to the purchase price of 8 mil polyethylene.

4. Seepage measurement. Evaluation of changes in canal seepage during the season using ponding tests is not practical because the canal cannot be taken out of service long enough for the tests. A joint ARS-University of Idaho study near Twin Falls, Idaho, indicated that tensiometers installed below the bottom of the canal could be used to evaluate changes in seepage rates as the canals seal by sedimentation. Variations in seepage rates during the season as influenced by management practices such as following "mossing" treatments with Xylene also can be evaluated using this technique.

B. Evaporation control and soil water movement

1. Inpondment evaporation control. Evaporation reduction by long-chain alkanol dispersions developed at the U.S. Water Conservation Laboratory, Phoenix, Arizona, was markedly superior to that obtained with powdered alkanol. This is contrary to opinions expressed by previous investigators who used less effective dispersions. Application of 1.1 g m^{-2} dispersed alkanol per month to outdoor tanks reduced evaporation 28 percent. The same application rate of powdered alkanol did not reduce evaporation. Increasing application of powder by 5 times reduced evaporation by only 15 percent.

A formulation has been developed for floating concrete blocks that will reduce evaporation from water surfaces. Durable blocks with a specific gravity of 0.5 were obtained with a mixture of Portland cement, perlite, and asphalt emulsion. There was no sign of water-logging after 6 months of floating. Average evaporation reduction on outdoor tanks was 50 percent when 75 percent of the water surface was covered.

2. Soil water movement. A study at the U.S. Water Conservation Laboratory, Phoenix, Arizona, was completed to determine the effect of interaction between pore walls and polar and nonpolar fluids on flow through fine pores, and to determine the effect of salts on the flow of water through these small pores (1.5×10^{-5} to 5×10^{-6} cm radii). The main conclusion from this study is that structuring of fluids due to interaction of polar molecules with pore walls reduces flow, but only to a small degree, generally less than 10 percent. Electrokinetic flow reduction occurs, but is also small.

Measurement devices and special equations have been developed to determine the amount of calcium in soil-water solutions that is "active" or available for reaction with the soil. It has been found that in a saturated calcium carbonate solution only 80 percent of the calcium is "active" while 20 percent is tied up in ion-pairs with carbonate and bicarbonate ions. The amount of active calcium is even less if other salts, such as sodium carbonate, are present. Previously it was assumed that all of the calcium was active, with resulting errors and confusion in research reports. These new findings will be of value in studies of soil aggregation and the movement of water through soil where the status of calcium in the soil-water solution is of paramount importance.

Studies have shown that the optimum application rates of water-repellent chemicals on soil surfaces may be readily determined by measuring the pressure needed to initiate water flow through these porous but water-repellent systems. This optimum rate is nearly the same for all soils when expressed as amount of material applied per unit of surface area for the soils. A method for measuring the contact angle of water on these treated soils was developed, and results using this technique support the findings obtained by measuring breakthrough pressure. Water-repellent chemicals have considerable promise for water harvesting and for improving irrigation efficiency.

Studies at Fort Collins, Colorado, showed the drying of soils and clays influenced the absorption of sodium ions. Dried clays and soils absorb only about half as many sodium ions as nondried clays when exposed to the same sodium-calcium solutions. This is attributed to formation of bundles of closely oriented clay platelets during the drying process and to preference of these internal surface adsorption spots for Ca^{++}. Soil-water movement in response to osmotic gradients was found to be small at soil-water suction less than one-third bar. Under these conditions, the osmotic efficiency coefficient (which indicates the efficiency of osmotic pressure gradient as compared to a hydraulic pressure gradient in causing water to flow) varied from 0.03 to 0.16.

C. Farm water supply systems and facilities

1. Water harvest. Date from the Granite Reef experimental site at the U.S. Water Conservation Laboratory, Phoenix, Arizona, indicate that hand clearing scattered brush can significantly increase runoff from similar low rainfall, low desert areas. Annual rainfall at Granite Reef averages about 225 mm. Brush clearing, at a cost of \$0.01 per m^2, has increased runoff by a total of 120 mm. during the 4 years following treatment. At least 40 mm. increased runoff will be obtained before reclearing is necessary. The resultant cost of the water is \$0.06 per 1,000 liters, which compares very favorably with any other water harvesting treatment presently available. Low cost brush clearing, which does not interfere with the use of the land for grazing, should be seriously considered as a water harvesting procedure in low desert areas where average annual rainfall exceeds 200 mm.

Laboratory studies indicate that several resin emulsions and solutions are promising low cost stabilizers for controlling soil erosion on catchment areas. These resins are rated as highly resistant to weathering degradation. One material completely stopped erosion of a highly erosive loamy sand soil by simulated raindrops when applied at a rate of 14 g resin per m^2. This represents a cost of less than \$0.01 per m^2 or \$40 per acre. The relatively small quantity of material required implies that application by airspray may be feasible.

Butyl sheeting exposed on the surface of the ground as a rain trap at Logan, Utah, is in good condition after 10 years use. Rain catchment areas covered with galvanized steel are in excellent condition after 4 years. The steel liners are mounted in contact with the soil surface.

Ordinary steel grain bins with plastic liners are being used for water storage. The roof serves as a supplemental catchment. Approximately 85 percent of evaporation is controlled by the roof as compared with a similar storage without a roof.

At Sidney, Montana, eight 25' x 25' butyl raintraps were installed in four pairs with each pair located on a different aspect, slope, and elevation with respect to a small natural drainageway on a range site. Various patterns of snow fences were installed with respect to four of the raintraps and on six other sites to determine the best pattern for maximum snow catch within the defined area. Raintrap catch varied as much as 0.26 inch per precipitation event among locations, but for the total period of measurement, any one raintrap did not consistently catch more rainfall. Essentially identical snowdrifts formed behind either a 4- or 8-foot high snow fence. However, maximum depth occurred 23 feet leeward of the 4-foot fence and 30 feet leeward of the 8-foot fence.

Studies at Gillette, Wyoming, and Nunn, Colorado, for small plots showed that sodium chloride-treated plots yielded runoff which was 37 percent of the precipitation compared with 18 percent on untreated plots. Plastic-covered pea gravel and asphalt roofing yielded 60 and 88 percent of the precipitation, respectively. The salt-treated plots caused erosion of 3,500 lbs. of soil per acre compared with erosion of less than 100 lb/acre on the check plots. In spite of much larger amount of erosion on the salt-treated plots, the electrical conductivity of the runoff water was slightly below that of the check plots.

At Akron, Colorado, runoff from 577 acres of contributing area averaged 0.75 inch in 1967. Collection of most of this water on 21.2 acres of level benches increased water supplies on the benches by 20.0 inches. Dry matter production of several crops averaged 4,820 lb/acre compared to 1,980 pounds on the check. Yield of most crops in the benches was partially reduced because of excess water just after seeding.

2. Surface reservoirs. Rainfall-runoff relationships on the watershed of 69.5 acres above a typical farm pond of 2.53 acres at Tifton, Georgia, on the Coastal Plain Land Resource area show that only a small percentage of the rain reached this pond in 1967 when rainfall was only 78 percent of normal. The 36.6 inches rainfall produced an input of 7.7 ac.ft. direct onto the pond and 15.1 ac.ft. inflow (7.1 percent of the rainfall) from the watershed. Output from the pond included 6.6 ac.ft. evaporation, 14.3 ac.ft. through the spillway, and 1.9 ac.ft. pumped for irrigation on part of the watershed. Evapotranspiration on the watershed was 197.7 ac.ft., or 93 percent of the rainfall. These data contrast with a yield to the

pond of 48.7 ac.ft. from 41.8 inches rainfall on 57 acres watershed in 1966. This was 24.4 percent of the rainfall as runoff and 75.6 percent as ET.

Subsurface geologic investigations show this watershed contains a phreatic aquifer 0 to 20 feet thick consisting of surface soils, Quaternary wind-lain sand, and weathered Tertiary sediments. The aquiclude below this aquifer is composed of tight clay and sandy clay. These investigations show that very little water is lost from the phreatic aquifer as deep seepage into the lower artesian aquifer.

Studies are continuing of hydraulic conductivity, porosity, volume of storage, specific yield, and other parameters affecting water yield on the watershed.

D. Systems for efficient utilization of the farm water resource

1. Land forming. In subhumid regions where total annual precipitation may be sufficient for adequate crop production, greatly reduced yields are frequently experienced due to poor distribution and losses of precipitation by evaporation and runoff. Improved methods for capturing and storing water for crop use are badly needed. From field research conducted at Brookings, South Dakota, geometrically shaping of land surfaces for improved water capture and utilization, it has been shown that contour listing and contoured 8-row bedding with lister planting increased potential water storage by 200 and 500 percent, respectively, over conventional contouring. Contoured 8-row bedding with lister planting offered enough water storage to eliminate the need for terraces with conventional contouring on 4 percent slope. Corn yields on plots with improved geometric shapes induced by tillage for water capture and storage were increased from 9 to 25 bushels per acre for listing and bedding treatments over conventional contouring.

2. Cut slope treatments. Studies with corn in Iowa during 1967 on land where the topsoil had been removed during construction of bench terraces indicated that there were factors limiting yield other than those that can be corrected by adding fertilizer. Corn without fertilizer yielded 13 bushels per acre on Ida silt loam and 6 bushels per acre on Adair silty clay. Addition of 120 pounds per acre of N and 44 pounds of P brought the yield to 53 bushels per acre on the scalped Ida and 39 bushels per acre on Adair. No response was found to K and Zn.

E. Reclaiming and use of wasted rangeland water

1. Soil characterization. Soils supporting greasewood plants are being characterized at Reno, Nevada, to determine feasibility of planting vegetation that would be of more economic value. The greasewood plants occupy small and large coppice dunes which are surrounded by barren inter-dunal areas. The small dunes are 4- to 6-inches and the large dunes

approximately 1-ft. above the surrounding interdunal areas. Evidently, greasewood plants play a part in the formation of a silica duracrust under the dunes, which is important from the standpoint of plant establishment and maintenance of seedlings growing in the soils. The soils are generally poor and highly dispersed with poor physical condition, high salts, sometimes high boron, and a varying water table. In general, the coppice dune areas are lower in salts and exchangeable sodium, are more permeable, and provide a better opportunity for revegetation than the interdunal areas. However, the soil properties are so unfavorable that the soils cannot be economically revegetated, unless they are subjected to expensive reclamation practices and then used for intensive irrigated agriculture.

Experiments at Reno, Nevada, indicate that tall wheatgrass can withstand much higher concentrations of boron than previously thought. In nutrient cultures under greenhouse conditions, the yield of tall wheatgrass followed an expotential relation over the range 0 to 150 ppm boron with a 50 percent decrease in growth occurring at 38 ppm B. This indicates the potential of tall wheatgrass for revegetation of the greasewood soils that are relatively high in boron if other soil and environmental factors were not unduly limiting.

2. Water use by native meadow species. Water used by native meadow species, saltgrass (Distichlis stricta), bluejoint (Elymus triticoides), and sedges (Carex spp.) was measured in 5-foot diameter by 6.5-foot deep steel tanks near Winnemucca, Nevada. Seasonal use (May 1 to November 1) was 22.6, 24.8 and 27.3 inches for the respective species when the water table levels in the tanks were fluctuated to simulate seasonal flooded or wet meadow conditions. An imposed management condition of drained soil, with irrigation whenever soil tension reached 6 atmospheres, resulted in a seasonal evapotranspiration of 25.3 inches from bluejoint.

Six years of water table hydrographs show that seasonal high water table conditions on the Humbolt meadow due to snow melt runoff and/or flood irrigation lasted from about 6 to 8 weeks. The high water table season can start as early as April 15 and be prolonged as late as July 15. Such conditions can be conducive to low hay yields and high water use rates.

3. Grass tetany disease. Studies are being conducted at Reno, Nevada, on the relation between composition of crested wheatgrass and grass tetany disease in cattle, and to correlate changes in composition with environmental changes which may increase the incidence of grass tetany. Analyses of samples taken at weekly intervals from first-greening until the grass headed out indicated that all potential factors which may cause grass tetany were maximized during the change from cool to warm temperatures. The ratio of potassium to calcium plus magnesium, the potassium, chloride, and the transaconitic acid content of the wheatgrass increased whereas the magnesium content decreased during this period. Other workers have indicated that forage containing less than 0.17 percent magnesium may cause tetany. The magnesium content of the crested wheatgrass was below

this critical level for considerable periods during the spring of the year, particularly during the change from cool to warm temperatures. Transaconitic acid has been suggested as a potential tetany factor with levels of greater than 1.0 percent hazardous. The transaconitic acid level in the crested wheatgrass was higher than 1.0 percent during the entire season of sampling, but was highest during the weather transition period from cool to warm. These data indicate it may be possible to predict the potential occurrence of grass tetany by measuring changes in air and soil temperature along with plant analyses.

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PRACTICES AND SYSTEMS FOR PREVENTING OR CONTROLLING CONTAMINATION OF SOIL AND WATER BY AGRICULTURAL CHEMICALS AND ORGANIC REFUSE

(RPA 901 - Alleviate Soil, Water, and Air Pollution)

USDA and Cooperative Program

Location of Intramural Work	Scientist Man-years FY 1968
Maryland (Beltsville)	13.2
Georgia	1.2
Louisiana	2.3
Ohio	0.9
Colorado	2.8
Nebraska	1.3
Oklahoma	0.5
California	1.0
Total	23.2

Intramural program is supplemented by extramural support representing (a) 1.1 SMY's at State Agricultural Experiment Stations, and (b) P.L.-480 funds in 1 country representing $14,998 U.S. dollars' equivalent.

Problems and Objectives

The types and amounts of agricultural chemicals used by farmers have increased rapidly in recent years. Although the concern about fish kills has subsided, there is still concern about pesticide residues in crops and soils. Increased use of commercial fertilizer and modern methods of handling livestock have caused concern about enrichment of waters. The increasing aerial levels of heavy metals (lead, cadmium, mercury, nickel, and chromium) are causing concern because of increased accumulations in plants and surface soils.

The purpose of this research is to extend our existing knowledge of the reaction of pesticides and other chemicals with soil and water, to understand their movement in soil and water, and to devise practices for controlling their adverse effects on these resources.

Progress - USDA and Cooperative Programs

A. Pesticides in Surface Runoff

The movement of pesticides into surface waters, subsurface waters, crops, and the surrounding countryside is of major interest to the public. In studies of pollution in runoff water at the North Appalachian Experimental Watershed, Coshocton, Ohio, conducted in cooperation with the U.S. Soils Laboratory, 0.03 p.p.b. of dieldrin (chlorinated hydrocarbon pesticide) was discovered in flow from land that had received none of this chemical. The land has been in trees for over 25 years. Where dieldrin had been applied in May 1967 at a rate of 5 pounds per acre on cropped watershed and mixed into the 3-inch soil depth, average concentration in runoff was 0.10 p.p.b. Only 40 percent of the applied dieldrin remained in the soil 16 months after application. Removal by crop, surface runoff, and erosion accounted for only a small fraction of this loss, and there was no evidence of movement of dieldrin downward below the normal plow depth. However, aerial contamination of the corn suggests that appreciable amounts may have been lost by volatilization.

Rainfall in the Coshocton area contained little or no dieldrin but was contaminated with DDT. The levels of inorganics in the rainfall remained substantially as in 1966.

Three watersheds at Riesel, Texas, in a rotation of oats, cotton, and grain sorghum were used to monitor pesticide residues in soil and loss in runoff and sediment. Preliminary results indicate that the amounts of toxaphene and DDT in both surface runoff and ground-water flow were very low (less than 1 part per billion) in all watersheds sampled. The concentrations of DDT decreased as the flow continued. No toxaphene was found in surface or ground water. Soil samples showed that toxaphene was concentrated

in the top foot of soil, whereas DDT was found throughout the soil profile. Between 10 and 20 percent of DDT and toxaphene applied during the past 10 years were recovered from the soil profile.

Studies at Watkinsville, Georgia, show that atrazine is transported in small, but significant, amounts in washoff from bare soil. The rain was applied 1 and 24 hours after atrazine applications with a rainfall simulator on a 5-percent slope. A concentration of 0.1 pound per acre or less was found in the washoff when the atrazine was applied to the soil surface at normal rates of 3.0 pounds per acre. The concentration was highest when the water was applied 1 hour after herbicide application and decreased as time before the water was applied increased.

Analyses of runoff water, soil, and plants where endrin was applied 0.3 pound per acre active material (150 p.p.b.) to sugarcane on Mhoon silty clay loam at Baton Rouge, Louisiana, show that by harvest time 0.1 percent was lost in runoff water, 5 to 6 percent was present unchanged, and 4 to 5 percent as degradation products in the soil after harvest, less than 1 percent was in the sugarcane plant, and 85 percent was unaccounted for. This was assumed to be lost through volatilization. The concentration of the endrin in the runoff water was 1.23 p.p.b. in the first runoff event after application, and 0.30 to 0.53 p.p.b. in the remaining five runoff events before harvest.

B. Loss of Pesticides by Volatilization

Because volatilization of the chlorinated hydrocarbon insecticides has been suspected in many experiments, studies were initiated at Riverside, California, on factors affecting movement and volatilization. Vapor densities of dieldrin (HEOD) in association with solid-phase dieldrin and dieldrin-soil mixtures were three to twelve times higher than predicted from published vapor pressure values. The vapor density and heat of vaporization of HEOD in moist soil at 100 p.p.m. were the same as that of pure HEOD, indicating that adsorption forces between dieldrin and soil are very weak, when more than a monomolecular layer of water is present. This implies that surface applications of dieldrin and other similar chlorinated hydrocarbons will probably volatilize as rapidly from the soil as from the pure material until the concentration at the surface falls to a level below 100 p.p.m. The concentration of dieldrin in the vapor phase drops very rapidly when the soil-water content falls below the equivalent of 1 molecular thickness of water. Water increases the dieldrin vapor density due to competition for adsorption sites on the soil, which explains the phenomena of greater volatilization of chlorinated hydrocarbons from wet than from dry soils. When greater than 1 molecular layer of water is present in the soil, the dieldrin is probably present as globules or adsorbed at the air-water interface. The vapor density of dry HEOD was the same as that of water-HEOD mixtures. This indicates that the so-called "codistillation" phenomenon is not due to an increased vapor

concentration in the presence of evaporating water, but is due to the concentration of chlorinated hydrocarbons at the air-water interface, both in water-hydrocarbon suspensions and in soil-dieldrin mixtures containing sufficient water to cover the particle surfaces. These data indicate that volatilization is a significant pathway for loss of chlorinated hydrocarbon insecticides from soils.

Laboratory studies at Fort Collins, Colorado, showed that loss of DDT from water by volatilization depends on the concentration of DDT/cm^2 of water surface. This loss appears to be independent of the amount of water lost by evaporation. The rate of DDT volatilization from water 1-cm. deep was about 1 percent per minute of the amount in solution. The chemical properties of the DDT molecule at the air-water interface indicate that the trichloroethane group is oriented towards the water surface. This portion of the molecule appears to exhibit a small residual negative charge, and a positively charged surface-active ion completely stopped the loss of DDT by volatilization. The adsorption of DDT on adsorbents was greatly increased by the presence of a positive potential on the absorbent. Anionic exchange materials, in all cases, adsorbed greater amounts of DDT than did cationic exchange materials. DDT was adsorbed on exchange resins so strongly that very little of it was exchanged upon the addition of sodium chloride or excess DDT. DDT was adsorbed to a greater degree on an anion exchange resin than was dieldrin.

In another study at Fort Collins, organic colloids from soils and leonardite influenced the volatility of lindane and DDT. Enhanced volatilization of DDT and lindane at higher temperatures indicates that the pesticides are held to the colloids by physical forces. However, at temperatures of 186°C., a considerable amount of pesticide was not volatilized and remained tightly fixed to the colloid.

Of interest to scientists and the general public is the persistence of pesticide compounds once they accumulate in the soil. In order to obtain some information on time of persistence, degradation products and methods of decontamination, a series of studies have been initiated in the Division. In a study at Fort Collins, Colorado, DDT exposed to intense ultraviolet light degrades to a number of products. DDE, DDD, DDC=O, DDOH, DDA, and BA have been identified, and three other products have been isolated but not identified.

In another experiment, the stability of DDE and DDD, degradation products of DDT, was determined by incubating the compounds in soil. Both compounds were very stable to both aerobic and anaerobic incubation conditions. DDE was slowly degraded in the aerobic system, probably by chemical catalysis. The limited amount of DDD degradation during anaerobic incubation was due to a microbial transformation. A gram-positive, spore-forming bacillus, capable of converting DDT to DDD, was isolated from soil amended with DDT, submerged, and incubated for 2 weeks. In thioglycollate medium, this organism converted 27 percent of the DDT to DDD in 9 days.

The persistence of pesticides in Cecil soil at Watkinsville, Georgia, was related to soil temperature and soil-water content, and to the type of material applied. The percentage of pesticide materials remaining in the soil 3 and 12 days, respectively, after application of the material was as follows:

Methyl parathion - in wet soil at 25°C. = 18 and 5; and in dry soil = 71 and 65.

Lindane - in wet soil at 25°C. = 90 and 84, and in dry soil = 95 and 91. In wet soil at 65°C. = 67 and 34, and in dry soil = 74 and 42.

Dieldrin - in wet soil at 25°C. = 96 and 96, and in dry soil = 97 and 97.

Concentration levels ranging from 0.5 to 5.0 p.p.m. in the soil had no effect on percentage losses with time. These higher rates of degradation in wet soil and under high temperature, conditions that occur frequently at the soil surface, suggest more rapid rates of breakdown than was formerly predicted by previous studies. Since these compounds do not move into the soil by percolating water, control of surface washoff should reduce the amount of these materials in water from agricultural lands.

At the U.S. Soils Laboratory at Beltsville, considerable progress was made during the year on developing analytical procedures for determining pesticides in plant materials. Satisfactory extraction methods were developed for fresh wheat and corn materials. With some plant materials, more than one extraction was required to remove all of the pesticides.

In a greenhouse and field study at Beltsville concerned with evaluating the significance of aerial contamination in the accumulation of dieldrin in corn and wheat from the soil, results showed that the leaves of the field-grown plants contained much higher concentrations than those grown in the greenhouse. The content in the stalks, kernels, and cobs was about the same in both experiments. Plants grown in the greenhouse were protected from aerial contamination from the soil, while no attempt was made to control this in the greenhouse.

In studying the adsorption of amitrole and prometone, adsorption was found to be influenced by soil acidity. Under mildly acid conditions, the retention by organic matter is more important than that by clay.

Little is known about the relation between pesticide decomposition potential of soils and the number of pesticide decomposing bacteria present. At Beltsville, a method was developed for studying the biological breakdown of dalapon. Results showed that the breakdown in five soils was not related to the total population of bacteria capable of this breakdown. Although volatiles from alfalfa have been shown to cause qualitative and quantitative changes in soil microflora, additions of these compounds to Drummer soil did not alter the rate at which dalapon was decomposed.

Public concern has developed over the discharge of lead and cadmium into the atmosphere from burning automobile fumes. Studies at Beltsville have shown that lead from automobile exhausts does contaminate plant and surface soil but does not move downward in the soil profile. However, soil cadmium derived from the same source is more mobile in the soil.

C. Contamination from Radioactivity

The program concerned with radioactive contamination of plant materials and soils from an accident or an atomic bomb has continued during the year at the U.S. Soils Laboratory. This past year, a method for immobilizing radiostrontium in soils with ammonium phosphate and fluoride has been tested in the laboratory and shows sufficient promise for evaluation in greenhouse and field studies. A computer program has been worked out for calculating the new equilibrium composition of the soil solution in many component systems whenever certain ions are removed or added. An immediate response to low doses of X-irradiation has been observed in the phytochrome system of barley root tips.

D. Ground-Water Pollution by Nitrates

Indication of ground water pollution by nitrates from feedlots, reported in 1966, prompted a series of laboratory studies this past year. In studies of nitrogen movement and loss in cattle feedyards conducted at Fort Collins, Colorado, laboratory model studies using columns of soil treated with different rates of urine and water additions showed that movement of contaminants through the soil was dependent on the management system. The only conditions where there was not substantial movement of contaminants through the soil occurred when the urine additions contributed less water to the soil than was lost by evaporation. In this case, all of the contaminants were kept in the upper 15 cm. of the column, and over 50 percent of the N added as urine was lost from the system as ammonia. When urine additions exceeded evaporation losses, lesser amounts of N were lost as ammonia and substantial quantities of pollutants moved through the soil.

Studies showed that urine moved thrcugh columns of Vona loamy sand with only minimal adsorption or separation of the nitrogen and carbon compounds. Creatinine, which accounts for about 5 percent of the N in urine, moved readily through the columns, but creatinine was broken down by microorganisms almost as quickly as urea N was hydrolyzed. Considerable quantities of nitrogen and carbon compounds were leached through columns of soil, even after urine was allowed to incubate in the upper 10 cm. of the column for 17 days at room temperature prior to the time leaching was started. These findings suggest that movement of pollutants through soil under feedlots can be prevented only by preventing water from moving through the soil profiles.

In studies of pollution from feedlots in Nebraska, laboratory investigations were conducted at Lincoln on the solubility and suspension of manures, using a 5-percent suspension and sampling after shaking at 0,1, and 24 hours. Highest solubility and suspension of volatile material were found in samples collected next to the feedlot bunkers. Appreciable numbers of micro-organisms of the pollution indicators were present. These micro-organisms remain in suspension even after 24 hours of settling. The amount of phosphorus and nitrate in suspension and solution remained high even after settling.

In response to questions raised about the contamination from chicken manure spread in large quantities on areas surrounding broiler- and egg-producing centers, an experiment was initiated at Watkinsville, Georgia. Poultry-house litter was spread in various quantities on the soil surface and the concentrations in runoff measured. The concentration of N as NH_4^+ in surface runoff from rains of less than 2 inches was increased as the quantity of poultry-house litter was increased up to 5 tons per acre and then decreased as the litter was increased on fallow Cecil soil with 7 percent slope at Watkinsville, Georgia. The mulching effect of the higher quantity of litter (wood shavings + manure) was overcome as the amount of rain was increased beyond 2 inches. Rainfall was applied at 2.5 inches per hour with a rainfall simulator. Measured losses in pounds per acre of N as NH_4^+ in runoff from 0, 2.5, 5, 10, and 27 tons per acre litter were 0.18, 3.79, 2.30, 0.02, and 0 for 1-inch rain.

Losses of nitrate N and ammonia N in runoff water were not related to rates of application of 100 and 200 pounds per acre anhydrous ammonia applied to sugarcane on Mhoon silty clay loam at Baton Rouge, Louisiana. Average concentrations were 0.38 p.p.m. NO_3-N and 0.83 p.p.m. NH_4-N. These N levels did not change with time from midsummer to autumn. The concentration of P in the runoff water was 0.15 p.p.m. in early August and only a trace by late September, showing that P content decreased with time during the season. Sugar production was reduced slightly with the higher application of anhydrous ammonia.

Collection of water from a seep which drains 7.8 acres of land at Riesel, Texas, has yielded some interesting information. There was some fluctuation at the beginning of the flow, but the concentration stayed level after that time. The level of nitrate was above the safe level early in the season. Most of the flow occurred during the first 20 days. These data suggest that significant levels of nitrate can leach through the heavy clay soil into the ground water. Nitrate-nitrogen in surface runoff was low except during the first runoff-producing storm which followed a long dry period.

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IRRIGATION WATER REQUIREMENTS AND USE EFFICIENCY AS AFFECTED BY CLIMATOLOGICAL FACTORS, SOILS, CROPS AND MANAGEMENT

(RPA 106 - EFFICIENT DRAINAGE AND IRRIGATION SYSTEMS AND FACILITIES)

USDA and Cooperative Program

Location of Intramural Work	Scientist Man-years FY 1968
New Jersey	0.7
Alabama	1.4
Florida	0.2
Georgia	0.4
North Dakota	0.8
Texas	2.1
Idaho	0.3
Washington	2.0
California	2.0
Nevada	1.0
Arizona	3.8
Virginia	1.0
South Carolina	0.5
Colorado	0.2
South Dakota	0.2
Wyoming	0.1
Total	16.7

Intramural program is supplemented by extramural support representing (a) 0 SMY's at State Agricultural Experiment Station, (b) 0 SMY's at other U.S. institutions and (c) P.L. 480 funds in 0 countries representing 0 U.S. dollars equivalent.

Problems and Objectives

The irrigated acreage in the United States totals about 44 million acres. This acreage will require 65 million acre-feet to satisfy evapotranspiration demands. An additional 30 million acre-feet are required to meet deep percolation, tail water runoff and evaporation losses during application. Approximately half of the ET requirement passes through the plant with the other half lost by direct evaporation from the soil surface. Practices to minimize these deep percolation and evaporation losses would greatly increase irrigation water use efficiency. Labor for water application is scarce and expensive. In the critical water short High Plains, rainfall averages close to ET requirements. Management practices for full use of the precipitation would greatly relieve the water shortage. Shallow rooting depth requires frequent irrigations and high evaporation loss for the soil surface. Optimum irrigation and fertilizer practices are dependent. Irrigations have been shown to effect crop quality. Seasonal drought and high off-farm production costs have increased the use of irrigation in the Humid area. Effluent from crop processing and sewage treatment plants must be disposed of without effecting stream quality. The potential for safe use of these waters for irrigation is not known.

The major objectives of this research are to provide technology for efficient use of irrigation water by:

1. Relating climatological, environmental and physiological factors to evapotranspiration.
2. Developing techniques to minimize losses to deep percolation and evaporation.
3. Developing soil and water management practices for increased water use efficiency.
4. Developing techniques for efficient use of rainfall and shallow groundwater to minimize irrigation water requirements.
5. Developing methodology and limits for safe use of various effluents as irrigation water.

Progress - USDA and Cooperative Programs

A. Evapotranspiration and irrigation water requirements

1. Advection. Strong advection of energy from the Pacific Ocean increased evapotranspiration rates above that which would have occurred due to radiation alone during the late fall at Lompoc, California. The ratio of evapotranspiration to net radiation (24-hour) was 1.20 at an irrigated rye grass site eight miles from the ocean during the period November 13 to December 18, 1967.

2. Evapotranspiration. Observations made during three seasons at Reno, Nevada, showed that: (1) Twice weekly (3- and 4-day) irrigations provided sufficient moisture for lawn grass grown on a sandy loam soil. Average daily ET ranged from 0.18 to 0.25 inches per day with an average seasonal use of 0.20 inches per day; and (2) Weekly (7-day) irrigations were adequate for the lawn grass grown on a loam soil. Average daily ET ranged from 0.15 to 0.26 inches per day with an average seasonal use of 0.20 inches per day. Evapotranspiration from Hybrid Bermuda grass (average for both soils during the last two seasons) ranged from 0.13 to 0.23 inches per day, with an average seasonal use of 0.18 inches per day for a weekly irrigation interval. The hybrids are better adapted to the Reno climate, with respect to stand density and color, than common Bermuda grass. However, the hybrids appear quite temperature sensitive and lose their color with slight frost.

At Reno, Nevada, standard pan evaporation, net radiation evaporation equivalent, and the Olivier and Penman methods provide comparatively accurate estimates of lawn and Bermuda grass ET on a monthly and seasonal basis. Average seasonal Blaney-Criddle coefficients (K), calculated from three seasons of measured lawn grass ET data, are 0.99 for the sandy loam soil, twice-weekly irrigation treatment; and 1.02 for the loam soil weekly irrigation treatment. Seasonal K for the hybrid Bermuda grass is 0.89.

A linear relationship was shown between plant density and annual evapotranspiration with Tifway Bermudagrass on Arzel fine sand at Fort Lauderdale, Florida. The formula $Y = a + bx$ expresses this relationship, where Y is the percent of ET from full sod and x is percent of sod cover. Values of the constants, a and b, were 110.5 and -0.075 for 12-inch water table, 44 and 0.56 for 24-inch water table, and 66 and 0.34 for 36-inch water table, respectively. These constants show the rate of water loss is proportional to the amount of ground cover, and is affected materially by depth to water table. Distribution of rainfall during the year also affected these values.

Evapotranspiration from cotton was 39.3 inches at the Drainage Research Farm, near Brawley, California, during the period April 5 through October 31, 1967. This amount was determined from daily measurements with a hydraulic-type weighing lysimeter which had a surface area of 100 square-feet. Gross measurements showed that 59 inches of water was applied to the 80-acre cotton field in which the lysimeter was located. Drainage accounted for about 14 inches. The 5.7 inch inequality between measured evapotranspiration and water balance calculations was caused by a combination of factors. These included a net gain in soil water storage, the under estimation of some missing daily lysimeter data, errors in the gross field measurements, and the probability that the stand of cotton in the lysimeter did not exactly represent the average of the wide variations of growth which existed in the field.

Large fluctuations in clear sky radiance previously observed at the U.S. Water Conservation Laboratory, Phoenix, Arizona, and reported in the literature were demonstrated to have been due to instrument malfunction. Typical real fluctuations were found to be so small as to require no corrections in the calculation of surface temperatures of soil and vegetation by means of infrared thermometry.

B. Minimizing losses to deep percolation and evaporation

1. Deep percolation. Detailed analyses of soil moisture data from irrigation experiments conducted at Prosser, Washington, from 1939-1952 indicate that the generally accepted design criteria of irrigating to refill the soil to field capacity may not result in the most efficient use of water. Unavoidable drainage from the soil between irrigations when irrigating to refill the soil profile may represent a substantial fraction of the depletion of soil moisture from 48 to 60 hours after irrigation until the next irrigation when high moisture levels are maintained and when evapotranspiration rates are low. Irrigation efficiencies must reflect this loss when leaching is not needed in addition to nonuniform distribution effects.

2. Infiltration. Low infiltration rates on fine sandy loam soils with furrow irrigation in the Columbia Basin have required excessively long periods of time to apply needed water. Studies at Prosser, Washington, indicated that cumulative infiltration was increased by the incorporation of straw or by shallow cultivation prior to irrigation. Cultivation was not quite as effective as 6 tons of straw per acre during the second irrigation, but was more effective than straw during the third and fourth irrigations. The increases ranged from 50 to 100 percent greater than the control. This study also indicates that the condition of the surface soil of the furrow plays a dominant role in these low infiltration soils. Infiltration rates also were greatly affected by the soil moisture level just prior to irrigation. A significant part of the low infiltration problem in crops frequently irrigated such as sugar beets and potatoes is probably associated with the high soil moisture levels maintained. Infiltration rates were 50 to 60 percent greater on plots that had not been irrigated for 3 weeks as compared to plots irrigated one week prior to the tests. There were no differences between similar treatments on a silt loam soil in the area.

The infiltration rate of plots on Cecil soil at Watkinsville, Georgia, which have been planted to corn for 3 years following sod in the previous 10 years, was significantly higher than that of plots planted to corn for 13 years and plots with a sod-corn rotation for 10 years. The soil physical condition responsible for these results and associated with 10 years of sod has persisted through the subsequent 3 years of corn cropping. The infiltration rate on the sod-corn rotation plots was intermediate. The duration of water application before runoff is rather consistently

lower for the continuous corn than for the corn following 10 years of sod. The trend toward a higher infiltration rate in the fall than in the spring persists.

C. Management practices for increased water use efficiency

1. Irrigation scheduling. In the Southern Great Plains, it is common practice to irrigate before planting irrigated grain sorghum to increase soil moisture storage and germinate weed seeds and wasted grain sorghum seed. Studies at Bushland, Texas, show that soil moisture storage was the same if the "pre-plant" irrigation was applied at any time between December and May. Better weed and volunteer sorghum germination was achieved by the spring irrigation in April and May than for the others. Only one-third to one-half of the pre-plant irrigation water was retained in the soil at sorghum planting time in June during years of below normal rainfall. In one preseason crop period, when rainfall was above normal, only 3 percent of the applied pre-plant irrigation remained in the soil at planting time.

Field experiments at the U.S. Water Conservation Laboratory, Phoenix, Arizona, have demonstrated the feasibility of using leaf temperature measurements as a guide for scheduling irrigation of cotton plants. In clear weather the temperature of freely exposed leaves ranged from 3° C. below air temperature shortly after irrigation to 3° C. above air temperature immediately preceding an irrigation that had been delayed sufficiently to induce moderate symptoms of midday wilting. The rise in leaf temperature can be used as an indication of the level of soil water depletion and the need for irrigation.

It is anticipated that sprinkler irrigation will be used extensively to irrigate adapted field crops grown on converted dry land areas in east central North Dakota (Garrison Diversion Unit). Irrigation studies on the Carrington Station show that nonirrigated versus irrigated barley yields varied from 25 to 85 bu/acre on well-fertilized plots with corresponding values for evapotranspiration (ET) of 6 to 17 inches. Corn grain did not mature but dry matter production ranged from about 3,800 to 8,900 lb/acre with a corresponding ET range of 7 and 15.5 inches. The ET values are essentially the same as results obtained during the period 1954-1956, inclusive, on the same irrigated crops grown at Upham, North Dakota. Various combinations of irrigation schedules, i.e., fall plus seasonal, seasonal, etc., had little effect on overall production where these treatments maintained ample soil water contents for optimum growth. Nitrogen fertilizers generally increased yields, especially on the wetter irrigation treatments.

2. Irrigating sugar beets. Daily afternoon wilt of sugar beets is common in many irrigated areas even though there is ample soil moisture. An experiment conducted at Twin Falls, Idaho, to evaluate the effects of daily intermittent sprinkling to control afternoon wilt resulted in no significant differences in beet root yield or sugar yield. The leaf area index tended to be larger on plots sprinkled daily during midday and yields were greatest on plots sprinkled nightly. This study also indicated that soil moisture tension at a depth of about 12 inches can be controlled at nearly a constant value such as 0.5 bar by daily intermittent sprinkling either during the day or at night. Crop responses under these conditions are not generally known since soil moisture tension in most irrigation experiments fluctuates between two limits.

Damage to sugar beet roots was manifest by the initiation of sprangled roots as early as mid-June at Carrington, North Dakota. Early season growth was slow and approximately 65 days (nearly one-half of the 136-day growing season) were required to produce the first ton of roots per acre. A maximum root growth rate of about 2.5 T/acre per week occurred in early August, but the growth rate declined steadily thereafter. Considerable new top growth occurred in September accompanied by renewed nitrogen assimilation and an increase in the leaf-area index from 4 to 5.

As in 1966, root and sugar yields were not significantly influenced by a clear plastic strip over the seed row from planting to emergence or by ridging as compared to flat surface planting. A lower percentage of the harvested roots were sprangled in 1967 than in 1966, and the nonirrigated plots had the lowest number of sprangled roots of all treatments. Plots plowed 11 inches deep had fewer sprangled roots than did plots that received shallower tillage.

Plowing depths between 8 and 32 inches did not affect sugar yields of sugar beets where adequate irrigation water was supplied in a study at Bushland, Texas. Nitrogen fertilizer increased sugar yield. The sugar yield without nitrogen fertilizer was 4,800 lb/acre. With 100 and 200 pounds nitrogen added per acre, sugar yields were increased 2,200 and 3,500 lb/acre, respectively. Nitrogen fertilizer increased water use efficiency by increasing yield without increasing water use.

3. Over irrigation. Water rights and historical practices of taking one's full allotment of water whether or not the crop requires additional water have not been conducive to encouraging efficient irrigation water management practices. Experimental data obtained during the past 4 years at Twin Falls, Idaho, have repeatedly shown that when excess water is used, more nitrogen fertilizer is required to avoid reductions in yields. Sugar beet yields, for example, in 1967 were 3 tons per acre more with only 50 pounds of nitrogen per acre when water applications were controlled as compared to plots where excessive water was applied. These data are essential to show the economic benefits of controlling

irrigation water which when coupled with lower rates of applied nitrogen will be necessary in some areas to reduce water pollution from agricultural areas.

D. Using rainfall and shallow groundwater to minimize irrigation requirements

1. Rainfall and limited irrigation. At Bushland, Texas, alternating 80-inch wide strips of wheat and grain sorghum are being studied as a means to conserve irrigation water. With adequate amounts of irrigation water, the grain sorghum in strips produced 14 percent more grain than solid planted crops. With limited irrigation water, two irrigations on strips produced more grain sorghum than three irrigations on solid planted sorghum. With adequate irrigation, wheat in strips produced about the same amount of grain as solid planting. However, with limited irrigation, wheat produced only slightly less with two irrigations on strips than three irrigations on solid planting. These data show the potential for using rainfall more effectively on irrigated crops in the Great Plains, yet maintaining high yield levels. The result is good yields with less irrigation water use on strips than on the conventional solid planted fields.

2. Using shallow groundwater. Grain sorghum was able to use substantial amounts of water from a 3-, 6-, or 9-foot static water table at Weslaco, Texas. Total water use by grain sorghum was about 12 inches. For the 3-, 6-, and 9-foot water tables, grain sorghum obtained 43, 14, and 5 percent, respectively, of its total use from the water table with a high moisture level, and 57, 42, and 19 percent with a low moisture level. These percentages are similar to the water use percentages obtained by cotton in previous tests. The low total water use, however, resulted from the short growing season for the sorghum which was during the spring instead of summer months.

Continuous soil moisture tension measurements made with recording tensiometers at Reno, Nevada, indicated usefulness of the method to measure water use from the groundwater. The studies were made in a buried tank containing loam soil that was planted to alfalfa. The tank was equipped with constant water level controls. A redesigned tensiometer cell eliminated the typical root concentrations previously observed around the ceramic bulbs. Tension measurements in the root zone were difficult to interpret because they appeared to indicate some value between that in the roots and in the soil. The study showed that recording tensiometers placed within the capillary fringe provided a means of measuring water use from a water table.

E. Effluents as source of irrigation water

A survey of food processing plant effluents was initiated at Norfolk, Virginia, to determine the composition of effluents from plants processing different food products. "Grab" samples were obtained from 10 plants processing tomatoes, 5 plants processing corn, and 4 plants processing sweet potatoes. Results indicate a great variability. Concentrations and relative compositions of organic and inorganic constituents in these effluents vary with the crop being processed, stage of processing and cleanup procedures. Sampling and analytical procedures are being developed to integrate these variables for the purpose of developing efficient land application practices for utilization and disposal of these effluents.

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IRRIGATION WATER APPLICATION FACILITIES AND SYSTEMS

(RPA 106 - EFFICIENT DRAINAGE AND IRRIGATION SYSTEMS AND FACILITIES)

USDA and Cooperative Program

Location of Intramural Work	Scientist Man-years FY 1968
Colorado	2.6
Idaho	7.1
California	1.0
Arizona	1.4
Louisiana	0.3
South Carolina	0.5
Nebraska	0.2
South Dakota	0.2
Wyoming	0.1
Total	13.4

Intramural program is supplemented by extramural support representing (a) 0 SMY's at State Agricultural Experiment Station, (b) 0 SMY's at other U.S. institutions and (c) P.L. 480 funds in 2 countries representing 30,489 U.S. dollars equivalent.

Problems and Objectives

Losses of water to the immediate farmer during water application have been estimated at 30 million acre-feet. This is enough to satisfy ET requirements of 20 million acres or nearly half of the current irrigated acreage. The scarcity and cost of labor to operate irrigation systems prompts the farmer to change set on a 12- or 24-hour basis whereas 6 to 8 hours would provide more efficient use of irrigation water.

Changing infiltration rates during application and as the season progresses had made design and operation of cutback systems difficult and largely unsolved. Sprinkler systems may promote surface sealing due to high velocity drop impact. In the humid area, many acres of otherwise highly productive land have periods of excess water that are followed by seasonal droughts. Combination drainage-irrigation systems have received too little research attention. Tail water return systems hold promise for reducing deep percolation losses as well as runoff losses. District and farm delivery systems need investigating to determine factors affecting efficiency of water use and to develop remedial measures.

The major objectives of this research are to increase the efficiency of irrigation water use by:

1. Developing criteria for design and operation of more efficient surface systems for manual, semiautomatic and automatic operation.
2. Improving sprinkler systems design for semi and full automatic operation including use of water of impaired quality.
3. Improving subsurface system equipment and operating procedures.
4. Developing methods for increasing district and farm irrigation efficiency.

Progress - USDA and Cooperative Programs

A. Surface systems

1. Automation. Automation of surface irrigation systems continues to challenge researchers looking for ways to reduce labor requirements and at the same time conserve irrigation water by using more efficient application techniques. Remotely operated, hydraulically-controlled butterfly gates installed in existing farm lateral turnout pipes and powered with water pressure developed from a water wheel or domestic water system have been successfully used to completely automate surface irrigated citrus groves on the Yuma Mesa, Arizona, and alfalfa-brome pasture near Fontenelle, Wyoming. Simplicity of operation makes the system attractive to prospective farm users. The irrigator or ditch rider need only open

the headgate on the supply canal to irrigate from 10- to 100-acre or larger blocks. More than one gate may be opened at a time to correspond to an irrigation set. When surface flow reaches a predetermined point down the irrigation run, a float-valve opens the gates on the next irrigation set. When water commences to flow through the butterfly gates on the second irrigated set, a float-valve just outside the ditch is activated to close the gates on the first automated irrigation set. This sequence is repeated until the entire automated area is irrigated. Automated irrigation systems of this type have been farmer-operated for one irrigation season.

At the Yuma Mesa Citrus Grove each irrigation set covers an area of two acres. The stream flow of approximately 17 cfs. is discharged through six 12-inch diameter turnouts installed in a concrete-lined ditch. The average time of application is about one-half hour per irrigation set, equivalent to an average depth of water of about 4 inches over the irrigated area. Since the farm lateral serves a 60-acre block of citrus, the minimum time that the irrigator must attend to the water is about 15 hours. Furthermore, water must be accepted when available and hence deliveries can occur during day- or night-time hours. The average cost for labor to irrigate one acre is $18.00 annually.

The automated system utilizes the existing turnout pipes and check gates, a source of water pressure (60-70 psi), solvent-welded 3/4-inch PVC pipe to distribute the water pressure at selected locations along the farm lateral, 4-way hydraulically-controlled pilot valves that operate double-acting water cylinders to open and close butterfly gates in irrigation turnouts, and sumps with sinking floats to operate 3-way control valves when surface inflow of applied water occurs at a predetermined point within the irrigated border strip. The automated system is completely hydraulic and can derive its operating pressure from a pump driven by a water wheel mounted in the flowing water being used to irrigate the land or a domestic water supply system.

A new center-of-pressure, fully automatic gate for use in unlined irrigation ditches was developed at Twin Falls, Idaho. The gate may be used as a safety gate or as a companion structure to other gates which create a rise in the water surface necessary for releasing this gate. A sinking-float border gate, for example, could be used with this gate to provide a fully automatic system for border irrigation.

Timers have been used for controlling semiautomatic irrigation structures. Most commercial timers have not been reliable when subjected to normal continuous exposure to dust and moisture. A commercial timer has been modified in cooperation with a manufacturer, to provide most of the necessary features of a controller of automatic or semiautomatic irrigation structures. It has a corrosion resistant movement and a factory-sealed enclosure and escapement release. It is currently being tested using a modified semiautomatic drawstring check (also now available commercially) in unlined ditches.

Field tests of an automatic cutback furrow irrigation system near Ault, Colorado, indicated that the outlets installed in lined ditches must be constructed to close tolerances and operated as designed because the secondary or cutback flow is very sensitive to variations in the effective head at each outlet.

2. Cutback systems. Irrigation specialists have advocated the use of cutback irrigation streams in furrow irrigation for many years, but this practice has generally not been adopted because of the problem created with the unused portion of the stream. Studies at Twin Falls, Idaho, have shown that a recirculating irrigation system and sump can be used to achieve the desired range of cutback streams by adding runoff water pumped from storage during the advance of the stream.

3. Runoff water quality. Runoff from irrigated fields has frequently been cited as the probable cause of poor quality water in some rivers. At Twin Falls, Idaho, samples of water from a sump receiving surface runoff during irrigations and compared with samples from the canal delivering water to the fields showed only a slight reduction in temperature, no significant changes in pH, electrical conductivity, and nitrate and phosphorous concentrations.

4. Drop structures. Commercial prefabricated drop-check structures are being manufactured by many small firms. Field studies of several of these structures near Twin Falls, Idaho, indicated that most of them are less stable and tend to wash out easier than more common built-in-place structures. Generally, the prefabricated structures do not provide adequate stilling basins for energy dissipation, or headwall length and depth for structural stability.

5. Water measurement. A mathematical procedure has been developed at the U.S. Water Conservation Laboratory, Phoenix, Arizona, to design highly accurate water metering flumes to fit a wide range of flow rates and channel conditions. The procedure eliminates the need for expensive flume calibration or conformance to standard dimensions. This has come about through a rigorous mathematical treatment of energy concepts that permits the successful theoretical prediction of calibration curves for critical depth flumes with a confirmed accuracy of $\pm$ 2 percent. Although the procedure is complex, it can be readily accomplished with computers.

Irrigation water measurement in lined-concrete ditches can be easily accomplished with cast-in-place concrete trapezoidal flumes having side slopes conforming to the standard slipform ditch. The form for casting the flumes, developed at Twin Falls, Idaho, was modified so that the height of the flume above the ditch bottom could be varied. This modification provides free flow conditions and results in greater ease of installation, elimination of feather edges; permits use of a lower slump concrete; and requires less hand finishing.

Detailed laboratory tests of a standard 9-inch Parshall flume conducted at Twin Falls, Idaho, indicated that the published calibration data for this flume apparently are in error. Parshall flumes with the throat and downstream diverging section removed have been used with the standard calibration for irrigation water measurement. Laboratory studies indicated that there is a significant change in the head-discharge relationship with these sections removed, particularly at high flows. This difference is not significant when the discharging jet is supported by the horizontal floor of a lined ditch.

6. Border systems design. Cylinder infiltrometer measurements used in design of surface irrigation systems to improve irrigation application efficiency were not adequate for fine-textured, irrigated borders seeded to grass and grass-legume mixtures in the Grand Valley, Colorado. When compared to intake amounts and rates for an entire border, values of a and b in the intake equation $d = at^b$ where d = depth were not statistically the same as among borders indicating that conditions affecting intake vary greatly from place to place in the field and from time to time. Constants for the advance and recession equations, $x = ct^n$ and $x_r = gt^h$, were not statistically the same among irrigations or among borders indicating dependence upon soil and crop conditions on a particular border at a given time. On a sandy soil near Fontenelle, Wyoming, similar measurements indicated that in 4 runs out of 9, cylinder infiltrometer data represented the entire border well enough so that errors in water balance were less than 10 percent. In 4 of the remaining 5 runs, infiltrated depths measured by cylinders were smaller than actual. Results show that cylinder intake measurements on sandy soils may be used for design of optimum length of border discharge and application time.

B. Sprinkler systems

1. Water distribution. Many companies are now developing and testing new methods of moving sprinkler irrigation pipe without the use of hand labor. One such system is the self-propelled continuous moving lateral. Studies of the water distribution by the self-propelled lateral at Twin Falls, Idaho, have indicated that water distribution is more uniform as compared to equivalent laterals operating at a fixed position for a given period of time. One of the major factors affecting the distribution is the fact that sprinkler heads on the moving lateral represent line sources of water for the field as compared to point sources with the standard nonmoving laterals.

C. Subsurface systems

1. Performance. Variation was encountered in amount of water applied by the various subsurface irrigation systems under investigation at Riverside, California. Some systems are requiring as much water as conventional surface applicator systems.

New plantings of citrus have been growing satisfactorily for 4 years on subsurface irrigation water and natural rainfall. Full grown trees produced slightly less under a subirrigation regime than did surface irrigated trees. A smaller quantity of water was applied by subirrigation. There is evidence of some salt accumulation in the soil around mature trees at the end of the 1967 growing season.

D. Increasing district and farm irrigation efficiency

1. Farm efficiency. A joint study of irrigation practices in southern Idaho being conducted in cooperation with the U.S. Bureau of Reclamation indicates that erratic timing of irrigations and applications of excessive amounts of water during irrigations are the major factors affecting farm irrigation efficiencies. Procedures for scheduling irrigations have been developed and are currently being tested throughout southern Idaho. These procedures are based on climatic parameters, soils, and crop characteristics using remote time-sharing computer facilities. The amount of water to be applied is also provided based on an attainable field irrigation efficiency. Results obtained in 1967 indicated that the farmer needs periodic information on soil moisture conditions and probable days before needing to irrigate in order to effectively utilize this information in making management decisions.

Irrigation of potatoes in the San Jacinto Basin using Colorado River water shows a greater yield and a greater percentage of large potatoes where soil moisture tension is kept low by frequent irrigation. Application of a slight excess of irrigation water when 0.25 bar tension is reached produced this result.

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DRAINAGE REQUIREMENTS, FACILITIES, AND SYSTEMS DESIGN

(RPA 106 - EFFICIENT DRAINAGE AND IRRIGATION SYSTEMS AND FACILITIES)

USDA and Cooperative Program

Location of Intramural Work	Scientist Man-years FY 1968
Vermont	2.0
Florida	0.9
Georgia	0.1
Louisiana	2.4
North Carolina	1.9
South Carolina	2.5
Minnesota	1.0
Ohio	1.5
Colorado	1.1
North Dakota	0.8
Oklahoma	0.3
Texas	0.3
Idaho	2.2
California	2.0
Nevada	0.4
Total	19.4

Intramural program is supplemented by extramural support representing (a) 0.8 SMY's at State Agricultural Experiment Station, (b) 0 SMY's at other U.S. institutions and (c) P.L. 480 funds in 0 countries representing 0 U.S. dollars equivalent.

Problems and Objectives

Nearly 100 million acres of wet agricultural land in the United States has been drained by open ditch, subsurface tile and pump systems. An additional 60 million acres are in need of drainage. An estimated 75 percent of current systems will need to be replaced by the year 2000. Current rate of installation is less than 600,000 acres per year or an expenditure of 50 to 60 million dollars annually.

Problems needing new or increased research attention include: drainage requirements for optimum plant growth, trafficability for farm operators and in the West for salinity control; knowledge of specific soil conditions to be created by the drainage system to meet the three requirements; quick, easy methods for securing soil characteristic values for use in water flow equation for system design; improved installation techniques and more easily handled material to reduce cost from $100 to about $60 per acre; improved anti-clogging devices and treatments to extend tile system life by 50 percent; systems improvement to provide uniform leaching of salt; and the utility of pump systems for dewatering and desalting the soil profile.

Major objectives of this research are to provide technology for the design of drainage systems to effectively meet the three drainage requirements by:

1. Completing technology concerning drainage requirements and systems for the major soil areas needing drainage.
2. Developing and evaluating improved surface drainage systems.
3. Developing design criteria for more effective and maintenance-free subsurface drain systems.
4. Developing and evaluating new subsurface drainage materials and installation techniques.
5. Evaluating pump drainage systems for removal of surface water and subsurface water and salt.

Progress - USDA and Cooperative Programs

A. Drainage requirements

1. Lower Mississippi Delta. Utilizing a water table depth control system on plots of Mhoon loam to clay loam at Baton Rouge, Louisiana, the growth rate and yield of sugar cane and cotton were measured in response to several constantly maintained water-table levels and to flooding treatments. Based on the initial crop a significantly greater net yield of cane was produced from the plots having the water table at 120 cm. than from those with a 60 cm. water table. In contrast, the cane from plots with a 60 cm. water table had a higher sucrose content than that from plots having a 120 cm. water table. Cotton on plots with a 100 cm. water table depth yielded significantly less than that on plots with water tables at 60, 80, and 120 cm. Plants on the plots with a water table at

100 cm. depth were also taller and had significantly more yield loss due to boll rot. The inversion of the yield response to water table depth curve seems to be a rather significant observation. Flooding about 3 weeks after first bloom for up to 72 hours did not affect cotton yield.

2. Southern Coastal Plains. At Florence, South Carolina, the effect of imposed water table levels and flooding upon the soil oxygen regime, growth, yield and rooting of field grown tobacco was measured. Tobacco grown with a water table maintained at the 30 cm. depth became chlorotic within 3 or 4 weeks after transplanting while that grown with a water table maintained at 46 cm. became chlorotic after 5 or 6 weeks. Foliar applications of nitrogen had no effect upon the chlorosis. Highest tobacco leaf yields were harvested from tobacco grown with a water table maintained at 61 cm. depth. Water tables at 30 and 91 cm. depths reduced yields by 18 and 12 percent, respectively. Roots proliferated all zones above the water table level with a tendency for a greater total weight of roots in the 61 and 91 cm. water table depth treatments.

Flooding of tobacco for 12, 24, 48 and 96 hours produced reduction in harvestable leaf yields of 13, 48, 65 and 70 percent. Foliar spraying during flooding with a 5 percent solution of $NaNO_3$ did not relieve the flooding effect. By 14 hours all depths below 8 cm. measured zero oxygen while the 8 cm. depth measured about 3 percent. These initial data indicate magnitude of tobacco yield reduction by flooding and high water tables.

In experiments at Raleigh, North Carolina, corn and squash grown with water tables maintained at several levels produced the greatest yields when the water table was 76 cm. below the soil surface. The water table level at 15 cm. reduced yields by 77 to nearly 100 percent.

3. Imposed gaseous composition of root environment. Measured responses of tobacco, cotton and Vicia faba L. at Raleigh, North Carolina, to various gaseous environments indicates that the oxygen concentration of the root environment alone is an inadequate gas composition criteria. It has been shown that tobacco is very sensitive to zero O_2 level but not very sensitive to high CO_2 particularly when the O_2 level is above 2.5 percent. In contrast Vicia faba L. is very sensitive to high CO_2 but not to zero O_2. Cotton is not injured by 72-hour treatments of pure N_2 or 1 percent O_2 with 20 percent CO_2 in N_2 while a 24-hour exposure to 21 percent CO_2 in N_2 kills it.

Other experiments have shown that the response to imposed gaseous environments around the roots can be significantly modified by the temperature of the root and shoot zone, the light intensity, and salinity level of the nutrient solution. High temperatures and light levels magnified the treatment effect upon tobacco plant processes. Increasing the salinity level tended to increase the tolerance of Vicia faba L. to high CO_2 and pure N_2.

Water uptake by tobacco in relation to gaseous composition in the root environment was studied at Raleigh, North Carolina. When intact tobacco roots growing in a nutrient mist culture were deprived of oxygen by replacing the atmosphere surrounding the roots with pure nitrogen or nitrogen containing 21 percent carbon dioxide the rates of water uptake decreased about 55 percent in 30 to 60 minutes and the plants wilted. The rates of water uptake remained at about 45 percent of normal during the 6-hour treatments but returned to near normal in 1 to 2 hours when oxygen was restored to the roots. The rates of water uptake decreased less than 20 percent when roots were similarily treated with gases containing 1 percent oxygen. Treatments with gases containing carbon dioxide gave the same response as treatments without carbon dioxide. The initial decrease in water uptake by tobacco in flooded or poorly aerated soil appears to be caused by anaerobiosis, the lack of oxygen. Carbon dioxide in concentrations that normally occur in soil has no immediate, direct effect on water uptake. The effects of oxygen on water uptake by tobacco indicate that the permeability of the roots to water may in some way be dependent on metabolic activity.

4. Inundation tolerance. In Chickasha, Oklahoma, damage to alfalfa by water inundation increased as the growth advanced from winter dormancy to maturity. A mid-April flooding to a 3-foot depth for 6 days severly retarded subsequent growth, whereas a similar mid-June flooding killed all plants. The 4-day June inundation suppressed growth. Flooding for 2 days at depths up to 3 feet during mid-April and mid-June increased alfalfa yields.

B. Surface drainage systems

1. Row grades and length. Surface runoff and yield of corn silage increased as row grade was increased and row length decreased on Mhoon silty clay loam at Baton Rouge, Louisiana. The row grades and lengths studied were 0.10, 0.15, 0.20 and 0.25 feet per 100 feet and 500, 700, 900 and 1100 feet, respectively. These findings suggest that for best drainage and yields the rows should be as steep as possible and as short as is economically feasible on the nearly level land of the Lower Mississippi Delta. Computations from one rainstorm of 2.04 inches that included extended periods of nearly constant intensity, showed that infiltration capacity of the Mhoon silty clay loam was 0.40 in/hr. or greater until about 1 inch of rainfall had entered the soil. Infiltration then decreased to less than 0.05 in/hr. These findings show that surface water disposal is essential during rains of large volume or frequent occurrence, both of which are common in this area.

2. Soil properties Atlantic Coast Flatwoods. Preliminary results of a ditch spacing study at Fleming, Georgia, indicated water levels in the soil midway between ditches were not related to ditch spacings of 60, 90, 120 and 150 feet on a reclaimed brackish water marsh in the Atlantic Coastal Flatwoods. The water levels ranged from +1.16 to -1.25 MSL during a 3-month period. Ground level was +1.17 MSL.

Also at Fleming, Georgia, studies show that physical and chemical properties vary widely in 18 important soil series of the Atlantic Coast Flatwoods. The wide variations in physical and chemical properties of these soils explain the extreme difficulty encountered in developing water and soil management practices in this area. The decline in agriculture and increase in timber production appears to be a natural consequence of these difficulties.

C. Subsurface drainage system design, performance and maintenance

1. Soil water movement. At Fort Collins, Colorado, experimental data from a 40-foot porous media flume (4 feet high) has indicated the possibility of adapting saturated flow theories to include significant capillary effects. If proposed modifications to saturated flow theories are valid, a method can be provided to accurately predict the performance of drainage installations. The need for such an analysis has long been recognized, especially for installations in fine-textured soils.

At Columbus, Ohio, it has been shown by theory and confirmed by laboratory model experiments that flow into a subsurface drain is less for a drain flowing partially full than for one that is flowing completely full. The decrease in inflow, as the flow in the pipe changes from completely to partially full, is attributed to the difference that occurs in the hydraulic head distribution around the pipe. For the case where the pipe flows completely full, the energy potential for moving the water from the soil into the pipe through cracks or perforations is greater outside than inside the pipe. For the case where the pipe flows only partially full, the energy potential in the soil immediately above the conduit is so low that there is no inflow from this region. For given hydraulic head and soil conditions, the net effect of drains flowing partially full is a reduction of inflow.

Laboratory studies were conducted at Burlington, Vermont, involving soil particle size distribution, moisture retention characteristics, and water uptake during freezing of soil samples from an interception drainage field study on the St. Lawrence-Champlain land resource area. Results show extreme variability of particle sizes within the area. Moisture retention characteristics indicate that the Ap horizon retained more moisture than subsoil layers. An erratic, modified step function pattern of uptake resulted during freezing of sand at low tension levels.

2. Tile discharge. Sixteen years of tile discharge records at Tiffin, Ohio, showed that tile depth had little effect on drain discharge, whereas, drain spacing and crop sequence significantly affected tile discharge. Discharge did not increase with greater drain depth at this location as normally would be expected because soil permeability decreased with depth. Drains at 30-foot spacing removed 50 percent more water per unit area than those at 60 feet. The kind of crop and the duration of growth the previous year substantially affected drain discharge. For example, drain

discharge during a corn year preceded by oats (short season) was 96 percent greater than when the preceding crop was second-year meadow (long season). This difference was attributed to the soil moisture storage or depletion carry-over effect from one season to the next.

3. Tile clogging by iron and manganese oxide. A survey of tile sealing due to oxides of iron and manganese in the Imperial Valley of California has shown the problem to be widespread geographically. Sealing occurs in all textures of soils and in all types of tile drains. Salinity and nitrate content of the tile effluent seem to be related to the occurrence of oxide deposits. Redox potentials, measured above tile depth, increased in a positive direction during the irrigation season. Those below tile depth became more negative. Low redox readings are indicative of the reducing conditions associated with tile clogging by oxides.

Treatment of one of the older tile drains on the Drainage Research Farm, Brawley, California, with a sulfur dioxide and water mixture resulted in a 23 percent increase in discharge. Inspection of the line showed that the treatment was effective in dissolving oxide deposits in the drain.

D. New subsurface drainage materials and installation techniques

1. Drain pipe strength prediction. At Columbus, Ohio, theoretical equations have been expanded and adapted for use to predict strength-deflection characteristics of flexible drain pipe for purposes of design. Whereas in the past, design of flexible pipe has been based on empirical tests and on "cut-and-try" design methods, it is now possible by use of these equations to directly design flexible drain pipes to withstand soil loads. The validity of the design equations has been established by a simple strength test method. This same test method will be useful for quality control in the manufacture of the pipe and will also serve as an inexpensive and a much simplified test for meeting specifications standards.

Both the test method and the theory will apply not only to drain pipe, but to other applications where small diameter flexible elastic pipe or tubes are subjected to soil loads. Results are independent of the kind of material used, so long as it is both a flexible and elastic material, and of the configuration of the pipe wall. For example, the test method and the theory may be used for both plastics and metals and for either smooth or corrugated wall pipe.

2. Installation equipment and techniques. With the new sub-draintube plow method of installing flexible corrugated plastic drain pipe, an accurate grade and depth control is needed for proper drainage installation and performance. The rapid installation (125 ft. per minute) of plastic drain pipe by the "plow-in" method was made feasible by the previous development of the laser-beam automatic grade control system (1966). An added development during the past year makes drainage machine operation and field equipment set-up easier and extends the usability of the control

system to different kinds of earth-moving machines. At Columbus, Ohio, a laser beam projection unit, which emits a thin laser light (approximately 1-inch thick) in a horizontal reference "plane" with a 13-degree angular spread, has been devised as a part of the newly developed automatic grade control system which is used on drainage machines for installing plastic drain tubes. By projecting this optically "fanned" laser beam over the field, where it can be received by an electronic detector mounted on the drainage machine, it is possible to install more than one drainline with each setup of the laser projection unit. In addition, steering of the drainage machine in a straight line is not required. It was developed for use on a sub-draintube plow but it may be used with other types of drainage equipment as well. For example, it can be used on conventional drain trenchers and on other types of equipment such as earth-moving and grading machines that travel across a field in irregular paths. With a single laser unit more than one machine can operate simultaneously in the same field.

If both elevation and guidance control are needed, which is desirable for a number of uses, the "spotlight-type" laser beam reference developed earlier, provides this capability. The "spotlight-type" laser beam can be easily obtained by simply removing the optical fanning lens from the telescope. The "fanned-beam" concept will also have application in other fields of endeavor, such as construction of dams, ponds, dikes, terraces, airports, highways, dredging rivers and harbors and other operations and projects for which a well defined and accurate reference plane or level is required.

The hydraulic control mechanism for use with the laser beam automatic grade control system is an essential component. In connection with the development of the laser-beam automatic grade control system for installing corrugated flexible plastic pipe, at Columbus, Ohio, a concept for improved performance of a simple on-off type control system has been discovered. The control can be described as a "pulsed-sampling-mode" type of feed-back control. As an on-off type control, its unique characteristic is that its electrical correction signals are precisely timed so that they properly couple with the lag characteristics of the physical hydraulic components of the control system to achieve desired operational characteristics. The concept used in this type of system may be useful for automatic control on earth-moving equipment and for many other applications not only in agriculture, but in industry and elsewhere, where control systems are utilized.

3. Materials to prevent sedimentation of subsurface drains. Present preventative and control measures have proved only partially successful, mostly because they have been developed on the basis of filtering action as a means of control. An entirely new concept by which sediment can be prevented from entering subdrains has been developed at Columbus, Ohio, (1966). It is accomplished by limiting the velocity of the water as it flows from the soil into the drain to a sufficiently low level that the sediment is not transported by the water.

This can be achieved by providing a water up-flow channel, just ahead of the water entry port (perforation or crack) in the subdrain. On corrugated draintubes it is done by covering the upper half of the pipe with an impermeable shield. The up-flow channel is formed by the valleys of the corrugations and this shield. The entry into the drain pipe is through perforations in the corrugation valleys along the top of the pipe.

For conventional tile drains (concrete and/or clay) the desired water entry velocity can be achieved by installing the tile on a pyramid-shaped layer of gravel in the bottom of the drain trench. An impermeable, yet flexible, cover (sheet-plastic shield) is placed completely over the structure formed by the tile and the gravel pyramid so that the edges of the cover extend to a level that is a few inches below the bottom of the tile.

Inspection of tile drains with different types of envelope material at Weslaco, Texas, showed the amount of sediment in various subsurface drains (concrete, bituminous, fiber and plastic) remained basically the same after 4 years as found after 2 years. No layering of sediment has been observed. Fine fibered fiberglass material used as an envelope on the drains lacked sufficient strength to withstand soil loads whereas no rupturing or tearing of the coarse fibered material was found. Compression of the coarse fiberglass mat was less than that of finer material. The greater thickness of the coarser material aided lateral water flow along the drain lines.

4. A modernized drainage system. The development of the sub-draintube plow for installing plastic drain pipe at Columbus, Ohio, has involved a systems approach. As a part of an overall drainage systems method, the various components have been planned, developed and reported individually as progress has been made over a period of several years. These components and the know-how for their use are now available to complete this new modernized method of agricultural land drainage:

a. Flexible corrugated plastic pipe.
b. Theory and testing procedure for proper strength design.
c. "Up-flow shield" over the top of the corrugated pipe to prevent sedimentation in noncohesive soils.
d. A sub-draintube plow.
e. Laser-beam reference, both "spot-light" and "fanned-beam" types.
f. An electronic "laser-beam receiver" mounted on the plow.
g. A hydraulic depth control system electronically activated by the laser-beam receiver.

It is estimated that even at present prices for materials the cost of drains as they are now installed will be reduced from 30 to 50 percent by this new material and new installation systems method.

E. Pump drainage systems

1. Sump drainage. At Florence, South Carolina, two years' results indicate this type of pump drainage is feasible for land depressions with no outlets. Slightly more water was removed where subsurface tile delivered water to the sump than where surface modification was the mode of water delivery. This increase in water removal was not reflected in increased yields, however.

2. Profile and artesian aquifer drainage. The problem of reclaiming salt-affected lands under limited rainfall conditions in the Red River Valley of North Dakota, has been the object of intense investigations over the past decade. Tile drains have proved ineffective and are extremely costly to install. Pump drainage also is costly to install but has the potential of influencing a much greater area. A drainage well installed in a salt-affected area during 1967 in the Red River Valley has shown that during an 18-day pumping period, a significant barrier became evident as the coefficient of transmissibility dropped from 46,950 to 24,100 gallons per day per foot after the fourth day. However, the potential effectiveness of the wells were reduced from 30 to 85 percent up to 3 miles away. If the present upward hydraulic gradient can be reversed by further pumping, there is a good possibility that reclamation can be achieved that heretofore has not been possible.

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SALINE, SODIC AND RELATED SOIL AND IRRIGATION WATER QUALITY PROBLEMS AND THEIR RELATION TO THE PLANT GROWTH PROCESSES

(RPA 103 - MANAGEMENT OF SALINITY AND SALINE SOILS)

USDA and Cooperative Program

Location of Intramural Work	Scientist Man-years FY 1968
California	15.0
Texas	0.5
North Dakota	1.0
Florida	0.4
Georgia	0.2
Virginia	0.5
Montana	0.2
South Dakota	0.3
Total	18.1

Intramural program is supplemented by extramural support representing (a) 0 SMY's at State Agricultural Experiment Station, (b) 0 SMY's at other U.S. institutions and (c) P.L. 480 funds in 1 country representing 113,370 U.S. dollars equivalent.

Problems and Objectives

Irrigation waters generally contain amounts of salts ranging from a few hundred pounds to several tons per acre foot. As consumptively used water leaves the salt behind in the soil, salt damage to crops and soils is an inherent and major problem of irrigated agriculture. Irrigated crop land in the United States has more than doubled during the last 20 years. Today 40 million acres are irrigated in the Western 18 states where salinity is a serious problem. In 1960 a survey showed nearly 30 percent of irrigated land was sufficiently salt-affected to adversely affect crop growth and that excess soil salinity was a potential hazard on about half of the irrigated acreage. Leaching to the ground water or to a subsurface drainage system continues to be the most practical means for removal of the salt. The resultant high salt content return flow increases the salinity problem for the down stream water user.

The major objectives of this research are to develop effective means for ameliorating and preventing accumulations of salts and exchangeable sodium in soils, decrease accumulations in water and minimize adverse affects on crops and soil by:

1. Increasing knowledge of water quality and the chemistry, mineralogy and biology of salt-affected soils.
2. Relating salinity to the state and transport of water and ions in soils and plants.
3. Determining tolerance and physiological reactions of plants to salinity.
4. Developing principles and practices for salinity control.
5. Developing practices for reducing salt delivery to the irrigated field and the down stream water users.

Progress - USDA and Cooperative Programs

A. Water quality and soil chemistry, mineralogy, and biology

1. Drainage water quality. At the U.S. Salinity Laboratory, Riverside, California, it was found that values for the sodium-adsorption-ratio (SAR) of drainage waters predicted by a semi-empirical equation were highly related to but about twice as high as observed values. The higher predicted SAR values were found to result from the fact that the semi-empirical equation does not take into account the dissolution of Ca and Mg from soil minerals that lower the SAR of the soil solution. The minerals involved (hornblende and plagioclase feldspars) are present in most arid-zone soils, and they lessen the sodium hazard of irrigation waters. A method for obtaining a numerical mineral dissolution coefficient was

developed. The coefficient was incorporated into the semi-empirical equation with the result that the steady-state SAR values of drainage waters can be predicted from the leaching fraction, and the SAR and a calculated pH value of the irrigation water. Results on salt solubility in a dynamic flow system indicate that, even for such highly soluble salts as $CaCl_2$ and $MgCl_2$, the dissolution rate is commonly of greater importance than is subsequent dispersion of the salt front in determining the rate of salt removal from soil columns. A useful dispersion index permitting comparison of breakthrough curves has proven to be a parameter analogous to the standard deviation of the curves.

B. State and transport of water and ions

1. Water potential. It was found at the U.S. Salinity Laboratory, Riverside, California, for Na-saturated Gila soil, the matric and osmotic water potentials are not independent of each other; the osmotic potential of adsorbed ions also contributes to the matric potential. Total and osmotic water potentials of pepper leaves decreased at the same rate as the root media as salination was increased, implying that turgor potential of the leaves did not change significantly with increasing salinity. Salinity caused a decrease in transpiration rate per unit leaf area apparently without changing turgor potential.

2. Instrumentation. Miniature thermocouple psychrometer probes have been successfully developed at the U.S. Salinity Laboratory, Riverside, California, to measure the water potential of intact leaves. A silver-impregnated conductive paint was found to be satisfactory for sealing the probes to leaves. A plant micro-environmental chamber that permits continuous measurement of photosynthesis, respiration, and transpiration has been developed and constructed to study the effects of salinity on water-use efficiency under different environmental conditions.

3. Movement of ions (Israel). Concentration dependence of the miscible displacement process has been studied, and tentatively linked to the anion exclusion volume. Laboratory studies of ion mobility in soils, and of conditions affecting the effective cation-exchange-capacity of soils, have been initiated. Super position of hydrodynamic dispersion effects on a piston-flow model for salt movement has been qualitatively verified with Hele-Shaw studies in sands.

C. Tolerance and physiological reactions of plants

1. Tolerance-humid area. Field studies at Fleming, Georgia, in a reclaimed brackish water marsh near the Atlantic Coast showed a distinct difference to salinity tolerance in varieties of soybeans. Germination and survival were excellent with Lee, only fair with Semmes, and a failure with Bragg varieties of soybeans planted on Capers clay loam 12 months after diking out the brackish water. Electrical conductivity values were about 12 mmho/cm and chlorine content was 3,000 ppm in this soil.

Growth of beans, corn and eggplant irrigated with waters having an EC of 0.3, 4, 8, and 16 mmhos were studied in Virginia. Water was applied by sprinkling the foliage or by flooding furrows between the rows. Growth of beans was reduced significantly at 16 mmhos but unaffected at other concentrations. Weight and length of ears of corn progressively decreased with increasing levels of salinity when sprinkled, but were unaffected when furrow irrigated.

2. Physiological reactions. Studies on sodium transport in corn at the U.S. Salinity Laboratory, Riverside, California, indicated that retention of the ion by living cells of the stele is a major factor in limiting translocation into the upper root and shoot. For five grape rootstocks, a correlation was found between chloride transport to the leaves and the percentage of charged lipids in the roots. Fatty acid analyses of root lipids revealed that rootstocks having higher rates of chloride transport contain relatively large amounts of polyunsaturated fatty acids. The chloride-exchange-capacity of lipids present in the membranes of grape root cells appears to account for observed differences in chloride transport to leaves. Removal of protein, lipids, and polysaccharides from root-cell surfaces by saline solutions decreases the uptake of solutes and the activity of some surface-located enzymes. The extent of damage to cell surfaces correlates with salt tolerance; beet cells maintain normal membrane functions at salt concentrations that destroy the semipermeability of the cells of the more salt-sensitive carrot. For 10 species of plants, growth in the presence of injurious amounts of salts had no effect upon either the amount of malate dehydrogenase enzyme in the plant cell or its properties. The activity of 15 specific enzymes in pea plants grown under saline conditions did not differ significantly from the activity in plants grown under nonsaline conditions. Claims that sulfhydryl compounds such as cysteine and thiosalycilic acid applied to plants increase their salt tolerance were not confirmed.

The effect of defruiting and boll load on the rate of flower production by cotton was studied at Brawley, California, using two well-established varieties, Acala Imperial and DPL-16 to evaluate the potential of flower and boll retention manipulation on productivity. Defruiting caused a marked increase in flow production. The boll load of cotton plants was inversely related to the rate of flower production during the summer "cut out" period. Defruited plants grew taller than fruited plants, primarily due to the shortening of internodes of the fruited plants during "cut out" rather than to increased numbers of nodes on the main stem of the defruited plants. The effect of the boll load on decreasing the rate of flower production appeared to be associated with the development of the square initials after initiation rather than before or during initiation. The fewest flowers were associated with wide spacing of plants, excessive vegetative growth, or a relatively high soil salinity. Soil salinity reduced the number of nodes and plant height of both fruited and defruited plants and resulted in decreased yields of seed cotton. In both varieties

peaks for boll retention tended to coincide with peaks for flower production. The rate of boll retention did not appear to be related to temperature or relative humidity.

3. Plant response (Israel). (a) For optimal growth atriplex thalimus requires slight salinization. It tolerates higher salt concentrations but osmotic potentials lower than -4 to -5 atm. retard growth. At osmotic potentials of -9 atm. to -14 atm. various changes in submicroscopic leaf cells appear. Salinity reduced the dry weight accumulation or increase in leaf area of beans. Iso-osmotic concentrations of Na Cl and Na_2 SO_4 affect these processes to the same extent, but beans under chloride salinity have thicker leaves and transpire less than plants under sulphate salinity.

(b) It is concluded that the level of cytokinin translocated to the shoot decreases as a result of water, salt and osmotic stress. It is likely that such a decrease is part of the change in the growth regulation mechanisms, and that a decreased level of kinins in stressed leaves is also responsible for their enhanced aging.

Kinins may well serve as Chemical messengers between root and shoot within the framework of the overall growth regulation mechanism of the plant.

D. Principles and practices for control

1. Leaching. For alfalfa irrigated with waters having salinities of 2 and 4 mmho/cm, at the U.S. Salinity Laboratory, Riverside, California, average yield per cutting increased linearly with increasing leaching percentage up to the leaching requirement calculated by the presently used formula. However, at comparable levels of leaching as dictated by the formula, yields were slightly higher with the irrigation water of lower salinity. This indicates that the presently used formula should be modified to take into account the specific effect of the irrigation water salt concentration. A leaching requirement formula for the prevention of harmful accumulations of exchangeable sodium has been conceived and a method developed for its calculation. The requirement is separate but analogous to that developed for salinity control.

At Fort Lauderdale, Florida, preliminary results indicate that soil salinity values fluctuate widely in the surface soil layers, but do not change below 8 inches depth in the Perrine marl soil. EC_e values (mmho/cm) in the top 2 inches of soil fluctuated from 12 when dry to 1.3 after rains and 0.5 after an extensive leaching trial. Similar values in the 2 to 6-inch soil layer were 5.5, 2.0, and 1.0. The EC_e readings were above 6.0 and nearly constant below 8 inches soil depth. The ground water in this area is highly dependent on rainfall amount, water level in nearby canals, and tidal fluctuations. The ground surface at the site was only 2.3 feet above mean sea level.

At Fleming, Georgia, where a brackish water marsh with Capers clay loam soil was reclaimed, the EC_e values (mmho/cm) of the 0-8 inch soil layer were 15 immediately after diking in September 1966, 13 in April 1967 before drainage ditches were installed, and 10 in November 1967. Ditch spacings of 60, 90, 120 and 150 feet had no effect on the EC_e readings.

2. Cropping. Management of surface soils and residues offers opportunity for reclaiming moderately saline soils under dryland conditions at Grand Forks, North Dakota. Over a 4-year period, continuous cropping with small grains, coupled with fall plowing, increased salinity in the 0- to 12-inch layer by 30 percent. In contrast, alternate cropping and summer fallow, coupled with standing stubble or straw cover during winter, reduced salinity of the surface soil by 71 percent. On a severely saline site, lesser changes in salinity occurred because of high water tables and very poor crop growth.

In Imperial Valley, California, cropping systems that included manure resulted in a 10 percent increase in sugar beet yields which were not due entirely to the nitrogen contribution of the manure. During the first cycle of the rotation no significant yield differences were observed that could not be ascribed to a nitrogen contribution from the cropping system. However, during the second and third cycles of the rotation sugar beet yield and quality increases, even when nitrogen was not limiting, indicated the cropping system that included manure was superior to those which included alfalfa or row crops without manure. Returning or removing crop residues made no significant difference in sugar beet yield or quality. The rotation including Coastal Bermuda grass resulted in the lowest beet yield at all levels of nitrogen fertilization due to reduced soil-nitrogen availability. The Bermuda grass plots, however, exhibited the best soil structure characteristics and lowest soil salinity, indicating increased water intake and leaching under this cropping practice. The cropping system utilizing alfalfa accumulated the highest amount of salt in the soil profile. The increased yields from the use of manure could be an important factor in promoting the use of manure in Imperial Valley which would help eliminate the waste disposal problem associated with large feedlot operations.

3. Tillage and amendments. Preliminary results from Mandan, North Dakota, suggest that the productivity of solodized-solonetzes can be increased by deep tillage and/or soil amendments. Plowing 12 or 24 inches deep in combination with sulfur application has reduced the sodium adsorption ratio of the soil and increased soil water storage. As a result, barley yields in one of the driest summers on record were increased in comparison with conventional 6-inch tillage. However, deep plowing without sulfur application so far has shown no yield advantage over conventional tillage in combination with sulfur or gypsum amendments. Sulfur and gypsum appear to reduce soil crusting and improve seedling emergence.

4. Temperature control following seeding. An experiment was conducted at Brawley, California, to determine the extent to which production efficiency of cotton might be increased by methods of increasing seedling growth rates. Plastic covers used to increase seedling growth increased maximum air temperature 3 to 14° C., and maximum soil temperatures by 0-7° C., at the 5 cm depth, and 0-3° C. at the 15 cm depth. Seedlings under the plastic covers grew much faster than similar seedlings not under covers during the cooler-than-normal growing season in the spring of 1967. Even though the differences between covered and open plants tended to decrease with time after the covers were removed, the early increase in plant size resulted in an increased lint yield of approximately 23 percent. These observations indicate that methods to improve seedling emergence and early seedling growth during cool weather in the spring may significantly increase production efficiency of cotton.

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SOIL EROSION BY WATER AND ITS CONTROL

(RPA 107 - TECHNOLOGY OF WATERSHED CONSERVATION AND MANAGEMENT)

USDA and Cooperative Program

Location of Intramural Work	Scientist Man-years FY 1968
Maine	0.7
New York	0.5
Georgia	2.6
Puerto Rico	.0
Mississippi	.0
Indiana	2.6
Iowa	0.6
Missouri	0.3
Minnesota	3.1
South Dakota	.0
Kansas	0.6
Oklahoma	0.6
Texas	0.6
Nebraska	0.2
Montana	0.5
Idaho	0.3
Oregon	0.3
Washington	1.4
South Carolina	.0
Total	14.9

Intramural program is supplemented by extramural support representing (a) 0 SMY's at State Agricultural Experiment Station, (b) 0 SMY's at other U.S. institutions and (c) P.L. 480 funds in 2 countries representing 29,986 U.S. dollars equivalent.

Problems and Objectives

Erosion by water remains the dominant conservation problem on 179 million acres of cropland and 32 million acres of non-Federal pasture and rangeland and on 240 million acres of Federal rangeland in the 48 mainland states. Erosion by water is an increasing problem on residential, industrial, highway and other construction sites. While raindrop impact contributes greatly to the erosion process, serious erosion only occurs with land runoff. An estimated 4 billion tons of soil material are carried by land runoff to streams each year. This sediment is the primary vehicle by which pesticides and plant nutrients move to pollute streams and lakes. Erosion reduces the productive capacity of land, makes farming by modern power equipment more difficult and costly, increases highway maintenance costs, destroys land, cloggs streams, reduces the water storage capacity of reservoirs, decreases the value of recreational lakes and increases stream and lake pollution.

The major objectives of this research are to develop effective control measures that are physically and economically usable on farms and construction sites by:

1. Increasing knowledge of the mechanics and principles of the water erosion practices.
2. Developing crop, mulch and tillage practices to provide cover and reduce runoff.
3. Developing topographic modification practices for increased water infiltration and safe removal of excess water.
4. Developing sediment traps, surface stabilization treatments and other means for temporary control of runoff on construction sites.
5. Developing practices to speed the establishment of plant covers.

Progress - USDA and Cooperative Programs

A. Basic mechanics, principles and prediction

1. Drop splash. Detailed analyses of raindrop-splash action at Morris, Minnesota, showed that the amount of material picked up from the surface by raindrop splash is affected by drop size, surface-water depth and, under some conditions, surface roughness or softness. Amount of splash increased with drop weight and with surface-water depth up to about one-eighth the drop diameter. The fraction of the falling drop that appeared in the splash formation also increased with drop size but decreased with increased surface-water depth to about one-half the drop

diameter. Surface roughness reduced splash amount when water depth was less than 2 mm, and softness of surface reduced splash amount when water depth was less than 5 mm. The fraction of the drop that appeared in the splash was little affected by surface softness and was unaffected by surface roughness when water-depth was 1 mm or greater.

In laboratory studies at Clarinda, Iowa, wash erosion from A and B soil horizons of land in continuous corn was measured to determine its relation to clod size. Contrary to expectations, total wash erosion in 90 minutes of simulated rain on 30 by 45 cm areas increased as clod size increased from the 0.5-2 mm range to the 8-30 mm range. This was found to be due to delayed peak-splash-rates on the larger initial clod sizes, which kept detachment high longer than on the smaller clod-size range. Splashed and washed material were both larger than material forming the seal. This indicates detachment from beneath the seal during raindrop impact.

2. Wind effects. The effects of wind on the shape, fall velocity, and energy of raindrops were studied in the wind tunnel-raintower facility at Manhattan, Kansas. Contrary to what might be expected, raindrops falling in the wind tunnel were shown to have less resultant velocity, kinetic energy, and momentum than drops of the same size falling in still air. More research is needed but it is speculated that this might be due to the fact that horizontal velocities of the raindrops attained only about 66 percent of the horizontal velocity of the wind in the short-duration exposures in the tunnel-raintower facility. Raindrop breakup began at windspeeds of 20 m.p.h., and increased greatly at speeds above 20 m.p.h., indicating that drop size distribution in higher velocity winds is influenced by drop breakup. While these results do not apply directly to natural rain, the prediction equations developed for resultant velocity and displacement as functions of drop size and horizontal windspeed will be useful in simulating and interpreting wind-rainstorms in the laboratory facility.

3. Crust formation. At Lafayette, Indiana, a laboratory study of 57 Corn Belt soils showed that the fine to medium textured soils were most susceptible to formation of crusts capable of influencing plant emergence and water infiltration. Crust strength, as measured by modulus of rupture, ranged from 0 to 601 millibars. Generally, crust strength was directly proportional to silt and clay content and inversely proportional to sand content and organic-matter level. Reduced water permeability due to rain-induced surface sealing was clearly evident on all but 2 of the 57 soils. The mean ratio of hydraulic conductivities of rain-exposed samples to no-rain samples was 0.41. A prediction equation made up of texturally-dependent variables and interactions of organic matter, soil aggregation and texture accounted for 97 percent of the observed variance in water permeability on rain-sealed soils. These results show surface sealing to be a major contributor to runoff and erosion on sloping soils of the Corn Belt.

Soil crusting studies conducted with a laboratory rainfall simulator in Maine to evaluate the effect of rainfall parameters and aggregate size on crust formations showed that an increase in drop size resulted in increased crust strength. There was no effect of aggregate size.

4. Flow detachment. At Watkinsville, Georgia, the force required to initiate movement of soil particles (the critical tractive force = CTF) for 13 Piedmont soils varied from 0.00487 lb/ft^2 for Appling clay to 0.00639 lb/ft^2 for Herndon silt loam. Five properties of the soils found to affect the CTF were % of sand 2.0 - 4.76 mm dia. (X_1), % of sand 0.05-0.105 mm dia. (X_2), % silt (X_3), % clay (X_4), and % carbon (X_5). The equation based on these factors for predicting CTF, with 95 percent accuracy, is:

$$CTF = 0.005986 + 0.000121X_1 - 0.0000857X_2 + 0.0000147X_3 - 0.0000161X_4 - 0.0000921X_5$$

These values represent bare soils in an unconsolidated state, as exists immediately following cultivation. Settled or protected soils should have higher CTF values.

5. Slope shape. Numerical analysis of effect of slope shape on erosion at Lafayette, Indiana, indicated that both sediment load and depth of erosion would be the least on slopes of concave shape, intermediate on uniform slopes, and greatest on slopes of convex shape. Total computed sediment yield was greater for a uniform slope than for a complex (upper half convex, lower half concave), but maximum depth of erosion was greater on the complex. All initial shapes developed toward concave profiles as erosion progressed. Mathematically derived profiles resembled natural field slopes more closely when threshold values were included in the equation, especially when the hypothetical slopes were short or gentle.

Hypothetical relations of soil-erosion rates to shape of slope were field tested under simulated rain in eastern South Dakota. Concave, uniform, and convex slopes were mechanically shaped on a deep loess (Crofton si l) soil. Convex slopes (steepening toward the bottom) yielded much more total sediment than uniform slopes, and those with concave shape were least erodible. Results of similar measurements on three soil types indicated that the slope effect is determined by the length of the slope and the steepness of a short segment lying immediately above the point of measurement. Soil particle movement within the plot length was determined by use of fluorescent glass particles and microrelief meters.

6. Prediction. An overland flow model based on the kinematic wave theory was developed at Lafayette, Indiana, for analysis of rainulator hydrographs to obtain unsteady infiltration data. The model includes retention storage, variable infiltration rates with respect to time and the portion of the plot covered with water, and a variable coefficient of friction.

Field data were used to estimate the retention storage and the coefficient of friction. In most cases, simulations made with a constant coefficient of friction compared well with field hydrographs. Retention storage had a pronounced effect upon the shape of the hydrograph. In cases of variable infiltration rates, this prohibited a simple time translation of the hydrograph to account for retention storage. The hydrographs could be separated into two parts: The part where the overland flow characteristics dominated the shape, and the part where the changing infiltration rate dominated.

Knowledge of basic relationships that define the capacity of each soil to infiltrate rain and resist detachment and transport by rainfall runoff is prerequisite to scientific design of measures to protect reservoirs and streams against pollution by soil from roadbanks, construction sites and farm fields. A functional equation was derived at Lafayette, Indiana, that expresses this capacity of a soil in terms of its physical and chemical properties. Tests verified the usefulness of this equation in meeting SCS's urgent need for locational values of the universal erosion equation's Erodibility Factor K for hundreds of soils on which research measurements have not been made.

At Lafayette, Indiana, soil properties and surface-condition variables were identified which, when combined in predictive equations, explained: 78 percent of the variance in amount of rainfall energy needed to start runoff from unprotected soils at 100 test sites; 79 percent of the variance in final infiltration rates under 2.5-inch rains; and 96 percent of the variance in soil concentration in the runoff. Rainfall, topographic, and soil management variables were identified which accounted for 85 percent of the variation in individual-storm runoff from corn land over a 10-year period on a Shelby loam soil.

Studies in Puerto Rico with a rainfall simulator showed that typical tropical soils were practically nonerodible by Southeastern United States' standards. Soil losses from 2.5 inches of rain applied at 2.5 iph (EI = 50) on dry to moist soil were 0, 0.2 and 1.0 ton/acre on fallow Humatas clay, Juncos clay and Pandora loam with slopes of 39, 37, and 27 percent, respectively. An additional rainstorm of 5.0 inches at 5.0 iph (EI = 200) caused soil losses of 0.5, 3.6, and 20.2 tons/acre on these fallow soils, respectively. Losses from tobacco with this storm on the same soils were 4.7, 0.8, and 8.3 tons/acre. The bulk densities of these soils were 1.00, 1.13 and 1.22, giving very high infiltration rates. It appears that raindrop impact energy is not a critical factor in the erosion process on these highly aggregated soils. Soil loss per EI ranged from 0.002 to 0.096.

7. Thermal effect. Erosion by water runoff from steeply sloping lands of the Palouse Region of the Pacific Northwest is most severe during late fall and winter seasons during which time much of the annual precipitation is received and when the soils are frozen or partially frozen. Studies

at Pullman, Washington, have shown that soil temperatures in the fall are higher under a mulch type tillage than on moldboard plots, but remain lower in the spring; the difference between the maximum and minimum temperatures or the diurnal amplitude is less; and the depth of freezing during a mild winter is less. A frozen soil that retained warm rainwater on the surface and remained permeable to water would thaw faster than a soil that had very little surface retention capabilities and was impermeable. The tillage (moldboard and chisel plowed) plots thawed more rapidly than standing stubble plots because they were more permeable to water. However, complete thawing occurred last on moldboard plots because the depth of freezing was the greatest. Thus a reduction in runoff and erosion due to frozen soil may be effectively accomplished by a tillage operation which leaves the maximum amount of residue on the surface (insulation, retention of water on the surface, and erosion resistant effects) and by maintaining the upper layers in a rough cloddy condition for greater permeability to water.

The movement of heat and water in the soils affects all aspects of plant growth. Damage to seedling by radiation freezing shortens the potential growing season and limits production in many areas. A series of seedbed designs were tested in the greenhouse and in the field at Twin Falls, Idaho, for their effectiveness in minimizing seedling loss by freeze damage. Planting in pockets 7.5 cm in diameter by 5 cm deep, formed in 45° south-facing slopes of 20-cm high soil ridges, resulted in leaf temperatures that were 3.4° C. higher than leaf temperatures under conventional seedbed preparation in the greenhouse and 2.2° C. higher under field conditions. This system could add up to 2 weeks to the effective growing season on the average in this area.

B. Crop, mulch and tillage practices

1. Cropping. The 16-year average annual rainfall at Tifton, Georgia, of 46.2 inches and 365 EI was close to the 49-year average of 47.5 inches and 350 EI for this location. Average annual water loss on Tifton loamy sand with 3 percent slope and 83 feet length was 11.8, 2.9, 1.2, 1.8, 2.0 and 0.4 inches from fallow soil; peanuts continuously; corn continuously; a 3-year rotation of oats, peanuts, and corn; a 4-year rotation of sod 2 years, corn and peanuts; and sod continuously, respectively. Average annual soil losses in tons per acre from these same cropping practices were 5.1, 1.2, 0.8, 1.0, 0.7, and 0.3.

Rainfall in 1967 at Watkinsville, Georgia, of 57.95 inches and 343 EI was 15 and 11 percent above average for these values. Runoff on Cecil sandy loam of 7 percent slope and 70 feet length was 19.3, 11.7, 6.0, and 3.4 inches from fallow soil, cotton continuously, corn continuously, and corn after Coastal bermudagrass sod, respectively, with all rows up and down hill. Contouring reduced these water losses on the cropped plots 24, 78, and 65 percent, respectively. Soil losses in tons per acre were 61.0, 21.7, 10.7, and 3.2, respectively. Contouring reduced the soil losses

from the cropped plots 55, 90, and 84 percent, respectively. These values show that both water and soil losses are controlled effectively with row crops following sod and with corn continuously on the contour (all residues were returned to the land), but are too high under other practices on terraced fields with 7 percent slope.

Rainfall in 1966-67 at Holly Springs, Mississippi, totaled 18.70 inches during the October-March residue period and 32.26 inches during the April-September crop period. EI values for these periods were 67 and 341, respectively. Soil losses from fallow soil, corn continuously with rows up and down hill, corn continuously with contour rows, and corn with up and down hill rows after bermudagrass sod during these two periods were 11.6, 0.4, 0, and 0.2 tons/acre and 73.9, 30.3, 1.6, and 17.1 tons/acre, respectively. These data show the need for cropping systems that provide protection to the land during the summer crop-growing period on erodible sloping fields.

During the second year of study, runoff and soil losses on the claypan soils at McCredie, Missouri, were again significantly lower from continuous corn with weed control cultivation than from corn with chemical weed control (no tillage after planting). Greater porosity of the surface soil and surface roughness on the cultivated plots allowed more infiltration and storage of water. Runoff during the corn-growing period was 0.35 inch from the cultivated plots and 1.49 inches from the chemically treated plots. Soil losses for the same period were 0.47 and 3.63 tons per acre, respectively.

In the first 2 years of a study at McCredie, Missouri, runoff and soil losses from continuous corn have been significantly higher when the corn was removed for silage than when the residues were shredded and left on the land until plowed down in spring. Cultivated continuous corn where the stover is removed for silage averaged 1.55 inches runoff and 1.68 tons soil loss in 1967, in contrast to 0.04 inch runoff and no measurable soil loss on comparable plots where the stalks were shredded after corn harvest. Where weeds were chemically controlled and the corn was harvested for silage, runoff was 4.62 inches and soil loss was 10.45 tons per acre.

Soil erosion investigations utilizing a rotating-boom type rain simulator were conducted at Ithaca, New York, on six plots having 15-year base differential treatments. An inverse relationship between erosion amount and aggregate stability was apparent. Low erosion values were obtained on plots receiving woodchip amendments and on plots broken from sod the previous year. High erosion values prevailed on plots that had been under intensive vegetable production.

2. Mulching. Farm lands in the Palouse region of the Pacific Northwest are characterized by steeply sloping fields that are clean tilled and subject to erosion by water when runoff from winter precipitation occurs. Protecting the soil with either standing stubble or the incorporation of crop residues in the surface layers is one of the most effective methods of increasing retention and infiltration of precipitation thereby controlling erosion. Stubble mulch tillage generally has not been adopted in the area in the past, but is being studied to determine if management practices can be developed to make this practice acceptable and economically feasible. Yields of winter wheat during the first year of a study varied with test sites, but on the average were lower on the chisel plowed and standing stubble plots than on the moldboard plowed plots because of cheatgrass infestation and competition from volunteer barley. Management practices are needed which will enable mulch-type tillage, but without the adverse effects that often accompany this method of tillage.

Near Pendleton, Oregon, wheat stubble left standing over winter resulted in storage of 1.3 inches more water in a 4.5-ft. soil profile than did plowed stubble. This additional water storage increased green pea yields 300 pounds per acre and also resulted in higher quality peas. Similar benefits were obtained when winter wheat was seeded in a cloddy seedbed as compared to a well-worked seedbed.

Erosion and runoff studies were conducted at Ithaca, New York, on plots growing corn comparing both zero and conventional tillage and length of time following sod. For first-year corn, the ratio of soil losses was 1 to 9 while for third-year corn, the ratio was 1 to 4.

3. Tillage. At Madison, South Dakota, till planted corn on erosion study plots under natural rain reduced both runoff and soil loss relative to conventionally planted corn. An average annual runoff reduction of 0.5 inch by the till planting resulted in an increase of more than 10 bushels per acre in average corn yield. Till planting on the contour conserved the most water during the growing season.

Studies at Columbia and Elsberry, Missouri, showed that crop response to different tillage methods varies with climatic conditions. Data for the period 1963 through 1967 showed that in years when wet and cold weather conditions followed planting corn yields were usually higher where tillage at planting time was shallow. During drier seasons with normal temperatures, corn yields were usually higher on areas that were deep tilled at planting.

Surface roughness and plow-layer porosity significantly influenced infiltration and soil loss in an Indiana study. Approximately 5 inches of high-intensity rain was required to produce runoff on a rough plowed soil, in contrast to 1/2-inch when the surface was smooth. A 5.6-inch rain caused only about 10 percent as much soil loss from the rough surface as from the smooth. Initial random roughness on the "rough" treatment was

twice that on the "smooth." These results indicate that any tillage system that leaves the soil surface in a rough (cloddy) condition would be effective in reducing runoff and soil loss.

In an Iowa study on Kenyon loam, soil loss from corn following fall plowed one-year meadow (corn-oats-meadow rotation) has been higher in each of the past 5 years than that from spring plowed continuous-corn plots.

Early stand establishment of fall-seeded wheat may provide erosion control on summerfallow land in the more humid regions of the Pacific Northwest. Recent improvements in equipment make seeding to moisture and rapid emergence possible on steep lands without depending on late fall rains to germinate the seed. Wheat seeded with a new version of the deep furrow drill during the second week of September emerged 7 to 10 days after seeding, and about 2 months earlier than wheat seeded at the same time with the conventional double disk drill. The early emerging wheat made substantial growth which provided considerable soil cover before the soil became cold. The late emerging wheat made little growth and provided essentially no soil protection because post emergence soil temperatures were unfavorable for rapid growth. The success and acceptance of early stand establishment depends on (1) maintaining sufficient soil water in the seed zone during the summer months when little or no rainfall is received, and (2) wheat production using wide row spacing which is necessarily a feature of deep furrow seeding.

4. Rain simulator. Comparison of rainulator storms with natural rainstorms of equivalent size and intensity on cultivated fallow plots at Morris, Minnesota, showed that soil loss from the rainulator storms averaged 78 percent of that from equal amounts of natural rain at comparable intensity. The rainulator applies 80 percent of the energy of natural rain. Therefore, the results of these tests support the authenticity of the EI variable as a quantitative measure of the erosivity of a rainstorm.

C. Topographic modification

1. Land grading for row grade control. At Holly Springs, Mississippi, on graded terrace interval plots with 150 ft. row lengths, both runoff and soil loss increased with slope where corn was grown continuously. With a 6-year average rainfall of 49.1 inches, runoff was 12.5, 13.7 and 17.7 inches and erosion was 3.7, 4.5 and 8.4 tons/acre on slopes of 2.5, 4.3, and 10.0 percent, respectively. Surface storage capacity in the furrows between the corn rows was 1.7, 1.9 and 1.6 inches of rain on the three land slopes in late summer of 1966. By early spring of 1967 these capacities were 1.6, 1.6, and 1.0 inches, respectively, showing a greater loss in capacity on the steeper slope.

At Temple, Texas, where a system of variable row length graded furrows is being evaluated as a water erosion control practice, previous years' data have shown that the system effectively controlled runoff and erosion and

produced above-average oat and grain sorghum crops which were not appreciably more difficult to harvest than on adjacent flat land. This year, the driest fall and winter during 53 years of record, provided an opportunity to observe the performance of the furrows under extremely adverse conditions. The oats crop on the graded furrows failed to germinate. Oats on nearby conventionally tilled areas did germinate but yields were extremely low. Because of the failure of the oats crop, the land was bare during most of the summer and soil losses were greater than normal. Average total losses from five storms were 1.9, 2.2, and 2.4 tons per acre for the 340-, 520-, and 930-foot row lengths, respectively. Analyses of 1965, 1966, and 1967 runoff data indicated a significant increase in unit storm runoff with an increase in furrow length. Similar analyses of soil loss data have failed to indicate a significant effect of furrow length on soil loss; however, it is believed that when additional years of data are available, a significant effect will be shown.

2. Terracing. At Cherokee, Oklahoma, where movement of soil into terrace channels and the effect of the terrace channel on sediment production were studied with variable length interterrace plots and paired concrete and natural channel terraces, data from 15 runoff-producing storms during the period August 13, 1964 to June 20, 1967 have shown that the terrace channel has very little effect on total soil loss and, in fact, may serve as a sediment trap. Average total soil loss from the 200-foot concrete-lined channels was 2.487 tons per acre. Loss from the natural earthen channels was 2.027 tons per acre or about 18 percent less than the concrete-lined channel. Results from the variable length interterrace plots showed that runoff and soil losses were greatest from the shortest and least from the longest lengths, indicating most erosion on steep back slopes and least erosion with some deposition on less steep slopes between terraces. Actual average total losses for the 14 storms were 3.1, 2.6, 2.1, and 2.1 tons per acre for the plots with lengths 33.3, 66.7, 100, and 166.7 feet, respectively.

D. Erosion control for construction sites

1. Waterways. Establishment of a protective grass cover on newly constructed waterways has been a problem in western North Dakota and eastern Montana. Studies at Sidney, Montana, have shown this problem is due to inadequate seedbed preparation of the densely packed cut portions of the waterway, low fertility status, and too deep placement of seed and untimely seeding of grass. Entirely satisfactory grass stands have been obtained on experimental waterways by chiseling the cut areas 5 to 6 inches deep, disking, and cultipacking prior to either drilling or broadcasting grass seed. The addition of 32 lb/acre of nitrogen plus 96 lb/acre of P_2O_5 increased production of second-year grass seedlings by nearly 60 percent or 118 lb/acre over the nonfertilized production of 203 lb/acre. Mulching with 2,000 or 4,000 lb/acre of straw did not result in improved grass stands but controlled water erosion from spring snowmelt. Adequate grass stands were obtained by either early spring or late fall seeding.

2. Steep fill slopes. Newly laid Kentucky bluegrass sod provided essentially 100 percent protection against water erosion from simulated storms on a 2.5:1 percent backslope of a conservation dam in eastern Nebraska. Added surface flows showed that damage can occur by undercutting. On fill slopes, wood shavings (2 T/acre) provided excellent protection and with asphalt compared favorably with jute netting used as a check. Wood excelsior (1 T/acre) and bark dust (2 T/acre) each anchored with 150 gallons asphalt provided less protection. A compost of metropolitan waste (2 T/acre) was only partially successful.

E. Plant cover establishment and maintenance

1. Fertility. Studies at McCredie, Missouri, show for sloping Midwest clay soils that adequate fertilization is mandatory for efficient and continuous production of corn, control of runoff and erosion, and high water use efficiency. In the 14th consecutive year of corn, runoff was 1.31 inches on adequately fertilized plots, 5.43 inches where only starter fertilizer was used, and 6.19 inches from unfertilized corn in a corn-oats rotation. Corresponding soil losses were 0.33, 1.44, and 2.00 tons per acre, respectively. These data were from corn plots on which a total of 6.74 inches of water was added in 15 applications to increase antecedent soil moisture before expected rainstorms.

The efficiency of moisture use on these claypan soils increased as corn yields increased. During the 14th consecutive year adequately fertilized rotation corn yielding 184 bushels per acre averaged 9.3 bushels of corn per inch of evapotranspiration. Continuous corn with comparable fertility yielded 183 bushels per acre and 8.6 bushels per inch of ET. Continuous corn receiving only starter fertilizer produced 14.0 bushels per acre and only 0.8 bushel per inch of ET. Soil moisture data showed that the adequately fertilized corn was able to extract 2.2 inches more water from the 24- to 48-inch soil depth, and 1.52 inches more from the 0- to 24-inch depth than comparable corn with starter fertilizer only.

Publications - USDA and Cooperative Program

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Crop, mulch and tillage practices

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SOIL EROSION BY WIND AND ITS CONTROL

(RPA 107 - TECHNOLOGY OF WATERSHED CONSERVATION AND MANAGEMENT)

USDA and Cooperative Program

Location of Intramural Work	Scientist Man-years FY 1968
Kansas	4.0
Texas	0.8
Montana	0.4
Minnesota	0.1
Total	5.3

Intramural program is supplemented by extramural support representing (a) 0 SMY's at State Agricultural Experiment Station, (b) 0 SMY's at other U.S. institutions and (c) P.L. 480 funds in 0 countries representing 0 U.S. dollars equivalent.

Problems and Objectives

Wind erosion remains a serious problem despite advances made in development of stubble mulching, strip cropping, shelterbelts, emergency tillage, cover crops, chemical soil stabilizers and other control practices. Since 1961 an average of 2.7 million acres have been damaged each year by wind erosion in the Great Plains. Damage to soils and crops occur each year on sandy and muck soils in the Midwest, Eastern Coastal states and the Columbia River Basin. Wind erosion lessens depth of top soil; reduces silt, clay, organic matter and nitrogen content of surface layer; reduces grain yield up to 85 percent by abrasion and 40 percent by removal of fertility and damage to soil physical conditions; reduces quantity and quality of vegetable due to destruction or damage by abrasion; and causes automobile accidents, increased highway, office and residence maintenance and respiratory infections in livestock and humans.

Major objectives of the research are to develop effective control measures that are physically and economically usable on farms and other affected areas by:

1. Increasing knowledge of wind erosion mechanics and principles.
2. Developing improved cropping, mulching and tillage systems.
3. Developing improved annual grass crop and tree barrier systems.
4. Assessing young plant response to sand blasting under various soil and climatic conditions.
5. Evaluating petroleum and chemical soil stabilizers under various crop, soil and climatic conditions.

Progress - USDA and Cooperative Programs

A. Basic mechanics, principles, and prediction

1. Analyses of wind velocity and direction data obtained at Manhattan, Kansas, from samples of winds from different directions and under stable and unstable atmospheric conditions showed that the degree of gustiness of atmospheric wind is primarily a function of average windspeed. At one foot above the ground, over 74 percent of the variance was accounted for by average windspeed. At 14 feet above the ground, 61 percent of the variance was accounted for by average windspeed. The amount of variability accounted for was not significantly increased by considering additional variables such as wind direction, time of day, Richardson number, or atmospheric pressure. Tests of normality of distribution showed that a substantial number of wind velocity and direction frequency distributions do not conform to a true normal frequency curve. Skewness was most evident in velocity distributions and kurtosis was most evident in direction distributions. A larger percentage of distributions obtained from the westerly (SW-W-NW) or northerly (NNW-N-NNE) directions

showed significant skewness or kurtosis than did distributions from easterly or southerly directions. Slightly more of the velocity distributions obtained under stable conditions were skewed than those obtained under unstable conditions.

2. At Manhattan, Kansas, the effects of surface roughness, mean windspeed, and free-stream turbulence intensity on the fluctuating velocity components in the turbulent boundary layer are under study as a part of continuing research to obtain better information on the forces and mechanisms involved when wind initiates soil particle movement. Data obtained thus far shows: (1) The longitudinal turbulence intensity at a given elevation is constant regardless of mean windspeed over a smooth surface in the boundary layer of a low-velocity wind tunnel; (2) over 99 percent of the variance in turbulence intensity within the boundary layer is accounted for by two dimensionless ratios, $\bar{u}_z/u_\infty$ and $\ln z/z_o$, where $\bar{u}_z$ is mean windspeed at elevation z, u_∞ is free-stream velocity, and z_o is roughness height; and (3) at an elevation of 1.5 mm. instantaneous windspeed could reach values 50 percent greater than the average.

3. Determination of wind erodibility index I' on representative soils from northwestern Ohio and completion of portable wind tunnel tests on on-farm sites in Ohio by the Manhattan, Kansas, Soil Erosion Laboratory provided significant information on the effects of soil texture and tillage and planting practices on erosion of soil by wind and useful information for improving the accuracy and applicability of the wind erosion equation. The Spinks and Ottokee loamy fine sands in northwestern Ohio are much more erosive than the Granby, Colwood, Oakville, and Tedrow loamy fine sands and fine sands and will require special intensive wind erosion control practices. The practices of planting corn on untilled cornstalks or after sidewinder or power disk tillage were much more effective in reducing wind erosion than were plow-disk-plant methods. The importance of planting rows perpendicular to prevailing wind was also verified by data which showed soil losses on Ottokee and Granby loamy fine sands to be three times greater with parallel winds than with perpendicular winds. Ohio soils are potentially more erosive than Great Plains soils. Differences were apparent for the full range of fractions greater than 0.84 mm. in diameter but were largest for soils having from 10- to 60-percent fractions greater than 0.84 mm. in diameter. Use of the table prepared from the erodibility index tests giving I' values in relation to fractions greater than 0.84 mm. in diameter is recommended when applying the wind erosion equation to Ohio conditions.

B. Crop, mulch and tillage systems

1. At Manhattan, Kansas, fabrication and assembly of a prototype tillage machine, tentatively called an impactovator, were completed which will permit intermittent or continuous packing of the soil just ahead of chisel tillage implements. The soil packing is to increase the cloddiness potential and thereby reduce soil erodibility. The machine has

10 impactors, each 4 by 6 inches in size, with two in-line ahead of each chisel tillage element. Power is transmitted to the impactors by the tractor power take-off through a right-angle drive unit and appropriate sprockets and roller chains. Motion is then provided by a cam and follower arrangement with compression-spring upstroke action. Stroke length is adjustable up to 4 inches and camshaft rotational speed is controlled by sprocket size and power take-off speeds. Preliminary operation of the machine in the laboratory under stationary, no-load conditions indicates that all moving parts are functional.

2. Research at Big Spring, Texas, to evaluate the effectiveness of the practice of spreading cotton gin trash to control wind erosion on Amarillo loamy fine sand showed that 5 tons per acre of trash is required to reduce soil losses to a tolerable 4 tons per acre per year. One ton per acre of trash reduced soil losses by 43 percent and 3 tons by 69 percent, both significant reductions but still nearly 5 and 2 times greater, respectively, than allowable losses. Tillage with chisels or listers without mulch reduced soil losses 50 percent below that from a bare, smooth soil surface and had some beneficial effect if done before application of amounts of gin trash of less than 5 tons per acre. Tillage did not have a beneficial effect in reducing soil losses when more than 5 tons per acre of gin trash was applied.

C. Barrier systems

1. At Manhattan, Kansas, micrometeorological investigation of the energy budget was conducted to characterize the influence of summer winds on the energy budget and to evaluate the influence of windbreaks on evapotranspiration. Data from two consecutive days in July were analyzed. An increase in maximum windspeed from 2.0 meters per second on July 29 to 4.5 meters per second on July 30 caused an increase in ratio of evapotranspiration to net radiation (ET/R_n) from 0.84 to 0.94 (open field). In the sheltered area 6H lee of the barrier the windspeed was about the same both days but the ratio of ET/R_n changed from 0.90 to 1.16, thus indicating that although the barrier caused a windspeed reduction, evapotranspiration increased. Further research is required to elucidate the influence of wind and shelter on evapotranspiration.

2. Five years of data from Garden City and St. John, Kansas, and 4 years from Colby, Kansas, are now available from tests of the potential of plant materials in single-row barriers for wind erosion control. Velocity profiles were measured and drag coefficients calculated on four barriers this year. Measurements of turbulence intensity, eddy size, and vertical velocities were also made in the leeward zone of the tamarisk barrier. The data indicated that this dense barrier increased turbulence intensity, decreased the eddy size, and induced mean vertical velocities. Tamarisk also provided the most resistance to wind and had a drag coefficient of 0.89. Pampasgrass was next in order of resistance with a coefficient of 0.56 followed by American plum and Siberian elm with coefficients of 0.52

and 0.46, respectively. The lombardy poplar trees have started to deteriorate, thus eliminating them from the list of promising permanent tree barrier. Otherwise, the list of most promising species remains about the same as reported in prior years. The Russian mulberry and honeylocust are the most promising of the trees. Pampasgrass and bamboo again were the most promising grasses. Caragana, American plum, common lilac, bush honeysuckle, tamarisk, fragrant sumac, and privet are the most promising shrubs.

3. Double-row barriers of tall wheatgrass established in intervals of 30 or 60 feet were effective in trapping drifting snow for subsequent storage of water in the soil root zone in a dryland experiment at Sidney, Montana. The water equivalent depth of snow trapped in stubble between the 30-foot barriers on February 28, 1967, was 6.7 inches; between the 60-foot barriers, 3.9 inches; and outside the barrier system, 1.0 inch. Corresponding values after a complete thaw of the original snow and a late April snowstorm were 2.2, 1.7, and 0.8 inches. The net soil water gain resulting from total snow catch plus 3.4 inches of rainfall prior to planting spring wheat was 6.9 inches between the 30-foot barriers, 6.5 inches between the 60-foot barriers, and 4.6 inches outside the barrier system. Soil water recharge within the two barrier systems was adequate to produce a spring wheat crop in 1967 without the necessity of summer fallowing. Soil erosion by wind is usually most severe on fallowed land; hence systems that permit continuous cropping are effective erosion control measures.

D. Sand blasting effects

1. At Manhattan, Kansas, continuing studies to evaluate windblown sand abrasive injuries to vegetable crops for purposes of establishing erosion tolerances showed that increasing the length of time that 4-week-old tomato seedlings are exposed to a 30 m.p.h. windspeed and abrasive flux of 0.2-ton per rod width per hour decreases dry matter production and increases the number of plants killed irrespective of pre- or post-exposure soil moisture level. High soil moisture plants were killed by being blown out of the soil where medium and low soil moisture plants were killed by soil abrasion. Fewer low soil moisture plants were killed by abrasion than medium soil moisture plants at less than 15-minute exposure time. Irrigation after sandblast injury will decrease plant loss and increase rate of recovery, e.g., 100 percent of plants exposed at low moisture (6- to 12-atmosphere tension) and held at this moisture level after exposure were killed but if the moisture level was raised to medium (1/3 to 6 atmosphere) and high (less than 1/3 atmosphere) after exposure, then plant loss was only 42 and 17 percent, respectively.

2. At Big Spring, Texas, continuing studies to evaluate windblown sand abrasive injuries to cotton and the effect of soil moisture on the recovery of damaged cotton plants showed that increasing the wind velocity from 900 to 1,350 cm./sec. (20 to 30 m.p.h.) and the abrasive flux from

0.1 to 0.5 gm/cm. width/sec. increased the cotton plant kill from 0 to 25 to 50 percent, depending on the soil moisture content and the plant age. Only 56 percent of the 3-day-old Western Stormproof cotton plants survived the abrasive injury but 72 percent survived when 9-day-old plants were exposed. Interactions were evident between effects of soil moisture, size of plant, and age at exposure. The larger 3-day-old plants in low (7 percent) soil moisture were most resistant to abrasive injury but the smaller plants in the higher (11 percent) soil moisture were most resistant. The reverse was true when 9-day-old plants were exposed with more small plants in the 7 percent soil moisture and more large plants in the 11 percent moisture surviving. This and previous research at the Station indicate that cotton plants have remarkable recovery powers and unless they are completely destroyed, they can recover and produce as much or more lint cotton as undamaged plants.

E. Soil loss tolerance and renewal rates

1. From headquarters at Manhattan, Kansas, measurements of the quantity and variability of dust deposited from the atmosphere since 1962 by a 13-station dust-deposition network which extends from the Rocky Mountains to the East Coast and from Texas to Montana show that the northern tier of stations receive the greatest quantities of dust in June or July, the central tier from March through June, and the southern tier from March through May with a secondary peak during August. Oxford, Mississippi, has two peaks, May and August, which are probably related to the growing season. The major factors controlling the quantity of dust deposition are: (1) Site; (2) season; (3) wind velocity; and (4) rainfall. Regression analyses using these variables accounted for from 40 to greater than 90 percent of the monthly variation at nine of the stations. Generally, sites along the western edge of the network receive the greatest quantities of dust, the pH and the percentages of silt plus sand are the highest, and the oxidation losses are the lowest. Conversely, the highest oxidation losses and percentages of clay are in the eastern and southern parts of the network; namely, at Coshocton, Ohio; Marlboro, New Jersey; Marcellus, New York; and Oxford, Mississippi.

Publications - USDA and Cooperative Program

Crop, mulch, and tillage systems

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MAINTENANCE OF SOIL TILTH FOR EFFICIENT CROP PRODUCTION
(RPA 102: Soil Structure; and Soil, Plant, Water Nutrient Relationships)

USDA and Cooperative Program

Location of Intramural Work	Scientist Man-Years FY 1968
Maine	0.3
New York	0.5
Georgia	1.1
Iowa	0.8
Minnesota	5.4
Colorado	1.5
Montana	1.5
Nebraska	1.3
North Dakota	0.5
Oklahoma	0.2
Texas	1.5
Idaho	0.3
Total	14.9

Intramural program is supplemented by extramural support representing P.L.-480 funds in one country, representing 4,230 U.S. dollars' equivalent.

Problems and Objectives

Soil tillage is a major production cost on most arable lands that are used for crop production. The cost varies from up to $30 per acre in areas used for vegetable production to less than $5 per acre for wheat production in the Great Plains.

The amount and type of tillage is determined by trial and error by the farmer. In the same soil, one farmer may place major emphasis on tillage while another will use minimum tillage.

With most crops, the soil tilth requirements for a good seedbed are not known and soil conditions required for managing water efficiently on the land are an unknown. The influence of different tillage practices on the management of crop residue and soil compaction also remain unknown.

The objectives of this research are to isolate and identify soil materials important in soil structure formation and define soil conditions and residue management required for plant development and water management. Post-planting tillage requirements will also be determined in these studies.

Progress - USDA and Cooperative Programs

A. Influence of Residues on Crop Production

Because large amounts of straw hamper tillage operations and sometimes reduce yields on irrigated lands, residue burning is a common practice. This loss of organic material is of concern to conservation-minded farmers and scientists. Studies recently initiated at Bushland, Texas, to determine the influence of residue management on small grain production showed that nitrogen fertilizer significantly increased grain yields while tillage practices (moldboard plowed, offset disk plow, and rototilled) had no effect. Nitrogen application made before the first tillage after harvest favored grain production and depressed residue production, while seeding time application had an opposite effect. Residue burning resulted in less soil-water storage than other tillage treatments.

In a continuing study at Twin Falls, Idaho, to determine the influence of nitrogen on the decomposition of straw, straw containing 1.75 percent N decomposed faster than straw containing 0.5 percent N when 15 tons per acre were applied. However, at the 5-ton straw rate, the rate of decomposition was the same for all straw.

These data suggest that large volumes of crop residues can be easily managed without burning.

During the year, studies have continued in the Great Plains to determine the influence of straw mulch on moisture storage. Results at Sidney, Montana,

for the fourth consecutive year show that surface mulch increases moisture storage. Amounts of water stored varied from 2.8 inches on the nontreated plot to 4.6 inches on the 6000-pound treatment. Morphological studies of the wheat plants showed that plants on mulched treatments contained significantly more tillers and adventitious roots per plant than those on bare fallow. Grain yields increased with the number of tillers and adventitious roots.

In continuing studies at North Platte, Nebraska, and Akron, Colorado, to evaluate the effects of residue, results show that the amount of soil moisture stored under mulched treatments increased with the amount of mulch. At Akron, an additional 1½ inches of moisture were stored under 3 tons of mulch as compared with the 1½-ton treatment. An additional inch of water was stored at North Platte under stubble mulch as compared with the treatment wherein the residues had been incorporated in the soil following harvest.

In studies at Mandan, North Dakota, conducted during a year of below-average precipitation, yields on mulched plots were 3 bushels lower than those on the conventionally tilled and plowed plots. Reduced yields apparently resulted from higher weed populations on the mulched plots. Nitrogen applications increased yields in all tillage treatments up to and including 120 pounds per acre. Of interest in these studies was that even at rates of nitrogen up to 120 pounds N per acre, the yields on the mulched plots were less than those on the conventionally tilled treatments.

Scientists and farmers have speculated that reduced soil temperatures account for the decreased yields under mulched systems. Studies conducted at Bozeman, Montana, to evaluate the influence of soil temperatures on the development of the wheat plant have shown that reduced grain yields occur when the temperature in the surface inch falls below 54 degrees F. for extended periods between tillering and boot stages. Analysis of the plant material for P, K, Ca, Mg, Mn, Zn, Fe, and Cu showed no difference in uptake between the various temperature treatments.

In similar studies at North Platte, Nebraska, soil temperatures below 46°F. for prolonged periods between tillering and heading resulted in lower grain yields. Data from this and the Bozeman studies suggest that soil temperatures may account for grain yield reductions in some residue management systems.

Results from all of these studies suggest that in addition to protecting the soil from wind and water erosion, crop residues can effectively be used as a soil and water management tool.

B. Influence of Tillage on Soil Temperature

In an attempt to determine why delayed seeding of winter wheat controls cheatgrass (Bromus tectorum), the influence of soil temperatures on the germination and emergence of winter wheat and cheatgrass was studied in

growth chamber experiments at Kimberly, Idaho. Temperatures were selected to simulate those prevailing at 6,000 feet elevation in southeasteastern Idaho. Species were seeded alone and in combination to determine if either affected the germination and emergence of the other. Results indicate that both species emerged over the same temperature ranges and that emergence of either specie was unaffected by the presence of the other. Thus, the effect, previously noted in field studies, where rod weeding followed by delayed seeding of winter wheat effectively controlled cheatgrass in dryland areas of southeastern Idaho, cannot be explained by differential germination of the two species at the lower temperatures prevailing during late September.

Farmers in the northern Corn Belt have frequently reported that corn germination was higher and seedlings grew faster on fall-plowed land than on spring-plowed land. In order to determine why this occurred, an experiment comparing the two systems was initiated at Lamberton, Minnesota. Results showed that the soil temperature at planting at the 2- to 4-foot depth was 2° warmer on the fall-plowed land than on the spring-plowed land. This soil temperature difference was reflected in increased seedling growth and early maturity.

C. Influence of Tillage on Soil Moisture

Wheat yields in the Great Plains are frequently appreciably influenced by tillage methods. Scientists have concluded that these differences result from moisture differences under the various systems. In order to evaluate the influence of tillage on soil moisture, an experiment was initiated at Bushland, Texas. In 1967, the results were different than those measured in earlier years. Wheat yields on fallow were higher with one-way plowed tillage and lower with delayed stubble mulch tillage. The latter tillage treatment loses moisture from weed growth during the summer following wheat harvest but has as much or more stored moisture at seeding time as other tillage treatments. In this instance, however, the deficit was never made up and thus yields were reduced.

Results at Ithaca, New York, continue to show that planting corn directly in sod killed with herbicides does not reduce yield and effectively conserves soil and water.

In most of the dryland wheat producing areas of the Pacific Northwest, water is by far the most important limiting factor in wheat production. Because of rainfall patterns, wheat frequently is planted in a dry seedbed. This results in germination as late as November. Late-germinated wheat makes very little growth before winter, produces low yields, and provides poor erosion protection during the winter and early spring seasons. Studies conducted near Lind, Washington, concerned with evaluating a dust mulch as a vapor barrier, indicate that a deep dust mulch (4.4 inches) results in lower soil temperatures and greater soil moisture at the seeding

depth than does a shallow dust mulch (2.2 inches). More rapid emergence and growth of fall-seeded wheat occurred under the deep than under the shallow mulch.

Investigation of soil-water storage as related to tillage-induced soil physical properties has involved measurement of thermal properties of soils associated with tillage at Morris, Minnesota. Improved estimates of the thermal properties of tilled layers have resulted from the use of a transient correction based on conditions imposed on the one dimensional heat flow equation. Measurements of air pressure difference over a plowed surface indicate that heat transport along air pressure gradients may penetrate 10 cm. into a plowed surface. In Minnesota, soil structural changes due to tillage have a greater influence on water infiltration than on evaporation control.

D. Soil Structure Formation and Persistence

The search for additional knowledge of the basic factors involved in the formation and persistence of soil structure continues in the Division. In studies at St. Paul, Minnesota, of periodic oscillations in the velocity of the convecting fluid in capillary tubes, the effective diffusion coefficient is shown to depend not only on the diffusion Peclet number but also on the waveform and generalized frequency of the oscillations. This work is being extended to include more complicated capillary networks and then will be tested on soils.

During the year, the influence of organic compounds on soil structure has continued to be studied at St. Paul. Experiments with the dextran B-512F added to Na-montmorillonite have demonstrated complexes that are partially resistant to chemical and biological oxidation. Although preliminary studies suggest that these compounds may be useful in agriculture, additional data are needed to determine their real value.

Results of studies of water retention by aggregate beds made at St. Paul, Minnesota, show that their primary influence is determined by properties of the materials comprising the beds, and are not appreciably influenced by water stability of aggregates.

Infrared spectroscopic studies of water absorbed in thin films between clay surfaces made at Watkinsville, Georgia, indicate (1) clay-adsorbed water is not bound by strong H-bond as in ice, (2) non-hydrogen bonded groups are evident in adsorbed water but not in bulk water, and (3) exchange cations affect the average H-bond strength in adsorbed water. These data, preliminary as they are, give some insights into the structural properties of water in thin films.

The first data obtained from a P.L.-480 study in India concerned with methods for characterizing soil structure indicate that optical techniques involving

microscopic thin sections have been successfully used in describing particle arrangements. However, this method has not been developed to the point of assessing its value as a tool for evaluating soil management methods for improving soil structure.

Publications - USDA and Cooperative Program

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Influence of Tillage on Soil Moisture

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Soil Structure Formation and Persistence

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NUTRITION OF PLANTS AS RELATED TO THE CHEMISTRY OF NUTRIENT ELEMENTS IN SOILS

(RPA 102 - Soil Structure; and Soil, Plant, Water Nutrient Relationships)

USDA and Cooperative Program

Location of Intramural Work	Scientist Man-Years FY 1968
Maryland (Beltsville)	9.1
Pennsylvania	1.0
Georgia	1.8
Puerto Rico	1.8
Colorado	5.5
North Dakota	1.0
Texas	1.8
Idaho	2.2
Oregon	2.0
California	1.5
Utah	1.0
Total	28.7

Intramural program is supplemented by extramural support representing P.L.-480 funds in 4 countries, representing $104,330 U.S. dollars' equivalent.

Problems and Objectives

Sixteen nutrient elements are necessary for the healthy growth of crop plants. The range in nutrient sufficiency varies from soil deficiency in all thirteen elements to soils containing sufficient amounts of all nutrients for maximum production. To meet the need for crop nutrients, approximately 39 million tons of fertilizer were applied in 1967, costing the farmers approximately 2.1 billion dollars.

Because insufficient information is available on an adequate method for estimating fertilizer requirements of various crops under the diverse climatic soil and climatic conditions that occur in this country, some soils do not receive sufficient amounts of fertilizers, while others receive excessive quantities.

The objectives of this work are to develop principles and practices for improving uptake of plant nutrients by more efficient fertilizer use and by increasing the nutrient supplying power of the soil. The possibility of altering the cycle and interchange of nutrients between the soil solution and the root interface as they may be affected by soil micro-organisms, crop residues, and soil organic matter transformations is also being considered.

Progress - USDA and Cooperative Programs

A. Efficiency of nitrogen use

Scientists continuing concern about low efficiency of N use in many soils and in many cropping systems has raised the question of loss by volatilization. These studies are difficult to make. Little or no data on nitrogen loss by denitrification have been made in the field.

Continuing studies at Brawley, California, concerned with denitrification of poorly drained soils indicated that gaseous N losses are closely related to soil redox potential (E_h). Anaerobic conditions induced in laboratory flasks by regulating the soil-water content and adjusting the helium-oxygen atmosphere in the flask caused large losses of nitrogen as N_2 gas. These losses increase as redox potential decreased, both with and without organic matter additions. In most cases, results collected by "in place" samples indicate that high concentrations can be expected near the soil surface but drop to zero at depths approaching the water table. These data suggest that high amounts of nitrogen can be lost as a gas. This information is of real interest to those scientists concerned with solving water enrichment problems.

Despite the sizeable past research effort, effort concerned with developing laboratory methods for predicting nitrogen mineralization that might occur in the soil, little progress has been made. Because this aspect of soil fertility is of such importance, a continuing effort has been made on this problem.

The current studies at the U.S. Soils Laboratory represent a considerable departure from the approaches, emphasized in most investigations on soil N transformations in soils, in which strong acid or alkali has been used to extract soil organic N for purposes of characterization. The development of milder extraction and fractionation procedures (sonification and hot water treatment) have centered attention on the labile fractions of soil organic N and is expected to permit more definite evaluations of the labile components and their transformations in soils than was possible with more rigorous extraction treatments. Use of tracer-N in biological and chemical studies of the types described above have shown that the methods under study, although still only an estimate, are an improvement over those methods used in the past.

Renovation and reseeding of wet mountain meadows in Colorado have always been difficult because of the accumulated sod mat that is resistant to decomposition by the indigenous micro-organisms. These sod mats involve up to 165 tons per acre of organic matter which contain up to 2.5 tons per acre of N. Studies at Grand Junction show that the basidiomycete (Marasmius oreades (Bolt), which produces fairy rings in lawns, has remarkable ability to decompose sod mats and liberate carbon dioxide and inorganic nitrogen. Future efforts will be directed to developing a system for enhancing the assimilation of the desirable micro-organisms under field conditions.

Because so many soil chemical, physical, and biological reactions depend on the organic fraction and so little is known about these materials, basic studies have continued at Corvallis, Oregon, on the chemical composition of organic matter.

Results indicate that simple refluxing of samples in 6 N HCl at 105° C. may prove to be a superior method of hydrolyzing amino acids from soil organic matter than is the sealed-container method commonly used by protein chemists for hydrolyzing pure protein. The refluxing method yields greater amounts of several amino acids than does the sealed-container method. Presumably, less degradation occurs under simple refluxing than under the prolonged sealed-container method.

B. Nutrient requirements of plants

Studies on the influence of nutrients on the quality of potatoes at Kimberly, Idaho, reported in last year's progress report continues to show that excess nitrogen is responsible for an increasing proportion of pointed-end tubers. Results this past season have shown that the effect of excess nitrogen was not overcome by applying phosphorus or potassium fertilizer. Currently applied and residual nitrogen were equally effective in causing the disorder. The future effort on this project will be directed to determining the nitrogen level to assure maximum potato yields without sacrificing quality.

At Weslaco, Texas, in an attempt to better define the nutrient requirements of vegetables in the Lower Rio Grande, multiple regression models expressing

yields of cabbage as a function of several parameters were developed. The two parameters, evapotranspiration and nitrogen supply, accounted for 72.6 percent of the variability in yield. Standard partial regression coefficients indicated that evapotranspiration was 2.4 times as effective than nitrogen in determining yields. Inclusion of more terms in the regression equation improved the effectiveness of the model. Sufficient data has now been collected to develop a mathematical model for predicting nutrient requirements of the important vegetables in the Valley.

The susceptibility of bell peppers to infection by bacterial soft rot was significantly increased by the application of nitrogen fertilizers at Weslaco, Texas. The nitrate-nitrogen content of the fruit petiole appeared to be a better index of susceptibility than the nitrate content of the pod or the total nitrogen content of either fruit petiole or pod.

In an attempt at Watkinsville, Georgia, to determine if cropping systems might be developed that will utilize the energy and water not normally utilized during the winter months, a successful association of cool and warm season grasses for extending the grazing season in the Piedmont has been demonstrated. In these studies tall fescue--Coastal bermudagrass associations have persisted for 4 years under N-fertilization rates of 500 pounds per acre when clipped to the 4-inch height or under N rates of 250 pounds per acre when clipped to the 2-inch height.

In other studies at Watkinsville, Georgia, forage yields of 4 tons per acre were obtained from either Coastal bermudagrass or bahiagrass on kaolin strip mine spoil the first year after establishment under good management and natural rainfall. Forage yields of 5 tons per acre were produced on slate belt soils in 1967 when rainfall distribution was poor. These findings offer a potential solution for vegetating strip mine and other problem areas which were formerly considered useless.

Extensive chemical characterizations of the major soil types of Puerto Rico show that K, Mg, and Mn contents vary widely within and among soil types. These findings are valuable in determining fertilization practices for grasses and liming practices for row crops. Star grass, produced for the first time in Puerto Rico, yielded 40 percent more beef per acre than did Pangola grass under similar intensive management. Star grass became established twice as fast as did Pangola and is apparently resistant to sugarcane aphid and immune to stunt disease. Although star grass shows high promise for pasturage in the hot, humid tropics, feeding trials must be continued to find out if its rather high HCN content is toxic.

C. Nitrogen recovery

In studies of nitrogen use at Mandan, North Dakota, on Eaken silt loam, an 8-year field study using various nitrogen studies showed that wheat yield was increased in most years by nitrogen fertilizer. Soluble nitrogen sources were superior to urea-formaldehyde in two of the 4 years in

increasing yield and nitrogen recovery. No gain in nitrate or ammonium occurred in soils where bromegrass was fertilized with high rates of nitrogen but did increase under fertilized corn. Recovery of fertilizer nitrogen applied at the rate of 80 pounds per acre annually over a 5-year period to crested wheatgrass was about 45 percent of that applied. Recovery was lower when the annual rate of application was 160 pounds. Over a 5-year period, native grass production per pound of nitrogen applied has been the same whether the nitrogen was applied all in the first year, all in the first 3 years, or in equal increments each year.

Studies on nitrification of urea at Mandan, North Dakota, show that more nitrite (sometimes toxic to plants) accumulates at 7° C. than at 14° C., and that nitrite accumulation is associated with high soil pH coming from urea hydrolysis. Only some soils will accumulate nitrite. Investigations at Fort Collins showed that organic colloids react with hydroxylamine and nitrous acid to fix considerable quantities of nitrogen. Carbonyl groups in soil organic colloids could react with hydroxylamine or nitrous acid to form oximes. Oximes react with $NaNO_2$ or nitrous acid to produce the gas N_2O. Dimethylglyoxime and quinone oximes were found to be exceptions to this classic chemical reaction, producing little if any N_2O. Soil organic colloid reaction products of hydroxylamine and nitrous acid were reacted with $NaNO_2$. The negligible amounts of N_2O produced suggest that if oximes are formed by the reactions of hydroxylamine or nitrous acid with soil organic colloids, the oximes probably resemble dimethylglyoxime or quinone oximes. This study suggests that soil organic colloid oxime formation and the reaction of such oximes with NO_2 ions is probably not a mechanism for nitrogen loss from soils. Improvements in the gas chromatographic separation of O_2, N_2, NO, N_2O and CO_2 were accomplished by use of two columns (Porapack Q and molecular sieve 5A) in series.

D. Plant metabolism of phosphorus

Studies of P metabolism by corn roots at Fort Collins, Colorado, have provided evidence that P uptake involves accumulation of newly absorbed P into an inorganic pool in the cytoplasm by a process which is ATP driven. Phosphorus in the inorganic pool enters rapidly into pools of soluble nucleotides and sugar phosphates. The inorganic P in the cytoplasm of roots is the pool from which P is translocated to the rest of the plant. Knowledge of form of P in plants and the energetics of uptake and utilization is establishing a sound basis for the development of diagnostic criteria for P requirements for maximum plant productivity.

The response of small grains in the Northern Plains to phosphorus is known to be associated with soil temperature. Field observations made in the Northeast suggest that responses of forages to phosphorus may also be associated with soil temperature. In order to evaluate this, growth-room studies were conducted at University Park, Pennsylvania, to determine the response of alfalfa adapted to both hot and cold climates. Results showed that higher levels of phosphorus were needed for a response when the soil was cold than when the temperature was near optimum.

At Fort Collins, Colorado, a method was developed to determine the fertilizer P requirement of various soils needed to equalize their P-supplying power to roots. With additional testing, this method appears to be applicable to a wide range of soils and is likely to yield information that would be more difficult and expensive to obtain by field or greenhouse experiments. The concept of ionic balance and the level of organic acids in the plant were applied in an effort to explain differences in maximum yields of five plant species on four soils. Differences in maximum yields between barley and sorghum were the most striking and interesting. The concept that a normal total cation minus total anion (C-A) content of 1000 me/kg. is a condition for good growth applies to the yields. On two calcareous soils (Terry clay loam and Cass silt loam), sorghum had an excessive C-A content accompanied by poor growth. This excessive C-A content relative to sorghum on the other soils was associated with a low K/Ca ratio in the plant. This imbalance of K and Ca apparently hindered the role of K in the movement of organic anions.

Results were reported in last year's annual report from a P. L.-480 project in Israel indicating that method and time of applying phosphorus and soil properties control fertilizer response. Additional data from the project has made it possible for the investigators to develop an empirical expression suitable for predicting phosphorus diffusion. In soils studied the equation satisfactorily predicted the phosphorus in the soil solution.

In another P. L.-480 study in Israel concerned with phosphorus nutrition, results obtained during the last year showed that the availability of phosphorus from soils with the same level of phosphorus varied with soil type. The scientists also observed that the percentage recovery of added phosphorus was not linear throughout a range of rates. The decreased recovery at the high application rates indicated that too large an application of fertilizer phosphorus may favor crystal growth. This information is a valuable addition to our knowledge of phosphorus nutrition.

E. Plant response to potassium

In many areas, the response of forage crops to potassium is extremely difficult to predict. Studies at University Park, Pennsylvania, showed that seeding alfalfa and orchardgrass separately in alternate rows greatly decreased competition for potassium. At high levels of potassium fertilization there was no apparent advantage of the alternate row seeding.

The soils of Puerto Rico's mountain region vary widely in their ability to provide potassium to grasses. Potassium has to be applied continuously to grasses in some soils, while pastures can produce at maximum capacity for many years without potassium fertilization in other areas. During the past year, considerable effort has been expended in the laboratory, field and greenhouse to determine how responsive soils might be identified. Results show that the Red and Brown Upland soils and the Granitic, Calcareous, and Clay soils of the coastal plains release large amounts while the Sandy Soils release very small amounts. These data are valuable in developing fertilizer systems for different areas on the island.

F. Micronutrients

At Fort Collins, Colorado, in a study searching for an inexpensive chelating agent for complexing zinc and boron, zinc soap was found to be equal but not superior to zinc sulfate as a source of Zn for three crops of corn grown in a greenhouse. These data point out the need for inexpensive chelating or complexing agent as a carrier of Zn to prevent the great fixation of Zn in fertilizers applied on most soils. Although triisopropanolamine (TIPA) effectively complexes boron and appears to make it nontoxic to plants, the high molar ratios of TIPA to B required make it an unpromising compound for the detoxiation of boron in soils and irrigation water.

Previous work at Fort Collins has shown that the utilization of N in wheat, corn, and beans is related to the S status of these plants. Continuing studies indicate that additional N did not affect either yield or protein level in S-deficient plants, but the nonprotein N (nitrates, amides, and amino acids) accumulated in such plants. One-part sulfur was required for every 12- to 15-parts nitrogen to insure maximum production of both dry matter and protein in roots and tops. These data suggest that as the use of nitrogen fertilizers increases, the possibility that sulfur may become limiting also increases.

At Bushland, Texas, residual yields from applications of 2,500 p.p.m. iron, 2,500 p.p.m. sulfuric acid plus 25 p.p.m. iron, or 250 p.p.m. iron plus 250 p.p.m. sulfuric acid in Arch soil were observed in the third crop of greenhouse-grown grain sorghum. In the field, similar yield responses were obtained on Arch soil with applications of 560 kg/ha. of iron or sulfuric acid. Phosphorus fertilizer decreased grain sorghum yield when applied without iron or sulfuric acid.

Beans grown in southern Idaho are subject to zinc deficiency and root rot infestation. The varieties most susceptible to zinc deficiency are also the least resistant to root-rot organisms. Research conducted near Kimberly, Idaho, using sterilized and unsterilized soil indicates that variable root growth exhibited by different varieties resulting from varying degrees of root-rot severity is not the primary cause of varietal differences in susceptibility to zinc deficiency.

G. Soil chemical properties

1. Influence of soluble silicate on reactions with nutrient cations

Studies conducted at Kimberly, Idaho, indicate that soluble silicate (unpolymerized silicic acid) reacts with some of the nutrient cations in dilute solutions to form sparingly soluble metal silicates. The composition of the precipitates varies with pH and concentrations of reacting constituents. A precipitate containing zinc and silicate forms above pH 7.0 and has a Zn/Si ratio of 2.0 or more. The magnesium silicate precipitate on the other hand forms at pH values above 10.0 and approaches a Mg/Si ratio of 1.0. The

silicate-containing precipitates of these metals form at slightly lower pH's than do the respective hydroxides.

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SOIL MICROBIOLOGICAL PROCESSES IN RELATION TO SOIL PRODUCTIVITY

(RPA 102 - Soil Structure; and Soil, Plant, Water Nutrient Relationships)

USDA and Cooperative Program

Location of Intramural Work	Scientist Man-Years FY 1968
Maryland (Beltsville)	5.2
Colorado	1.2
Nebraska	0.5
Idaho	0.3
Washington	1.1
Total	8.3

Intramural program is supplemented by extramural support representing P.L.-480 funds in 2 countries, representing $38,172 U.S. dollars' equivalent.

Problems and Objectives

All phases of soil science are related in some way to the microbial populations in the soil. The fact that native grasslands are inherently high in nitrogen is associated with the various strains of Rhizobia in the soil-root interface of the cover that once made up the range. Many of our soil pathogens are microbial. We depend on soil microbial populations to dispose of the huge amounts of residues that accumulate in the production of food and fiber. Recently, we have become quite concerned about the role of microbes in detoxifying our soils after they acquire an accumulation of chemicals or animal wastes.

The objectives of this work are to gain a better understanding of the environment desirable for Rhizobia, to determine the factors that affect pathogenic organisms in soil, to determine the role of plant residues and their decomposition products on microbial activity and growth, and to find ways of utilizing microbes to detoxify soils contaminated by pesticides and other pollutants.

Progress - USDA and Cooperative Programs

A. Influence of Plant Volatile Substances on Microbial Ecology

Previous work has demonstrated that volatile components of plant residues play an important role in the ecology of soil micro-organisms. During the past year, the effect of volatile substances found in plant materials on respiration, growth, and survival of micro-organisms in soil was studied in detail. Low concentrations of volatiles from alfalfa stimulated microbial respiration in all soils tested, caused fungi to break dormancy and grow vegetatively in soil, and led to increases in microbial populations. Higher concentrations were toxic to the general soil microflora, but a wide range in sensitivity was found among the soil fungi. The plant pathogen Verticillium dahliae was killed in soil by high concentrations of crude alfalfa volatiles. Its population was reduced even by low dosages because they induced a temporary multiplication followed by a more rapid death rate. The four most active substances in the alfalfa volatile mixture were identified as acetaldehyde, isobutyraldehyde, methanol, and ethanol. Other low molecular weight aldehydes and alcohols were also similarly active, some more so than the above. These previously overlooked substances may prove to be valuable tools in manipulating microbial processes for better crop production.

B. Inoculation of Legumes

In an attempt to determine the environment necessary for an effective Rhizobia to survive in problem soils, an apparatus for effectively conducting Rhizobium trials has been developed and employed successfully

in studies at Prosser, Washington. The apparatus essentially eliminates contamination by wind-carried organisms which is often a problem encountered with conventional equipment used in effectivity studies.

During the first year of study in a P.L.-480 project in India, the investigators observed that inadequate nodulation of certain pulse crops is common. Rhizobium strains, especially for the cultivated species, have been isolated. Future studies will be concerned with testing these isolates and retain those which are efficient nitrogen fixers.

In a P.L.-480 project in Poland, the emphasis has been placed on studying the genetics and toxonomy of Rhizobium. The first successful transduction of Rhizobium was done in this study. The highest frequency of transduction was obtained in media containing yeast extracts. This information should be very useful to those doing transformation or transduction work in the United States.

C. Root Rot Organisms

Foot rot or root rot organisms (Fusariam roseum f. sp. cerealis "Culmorum") cause large losses in wheat yield in the Pacific Northwest dryland areas. Experiments conducted in Florida suggest that anhydrous NH_3 injections reduced the total soil fungi. Research conducted in the laboratory and in the field at Pullman, Washington, concerned with determining the concentrations of injected anhydrous NH_3 on fusaria species shows that injection of liquid anhydrous ammonia into the soil markedly decreases the number of spores remaining viable in the zone of ammonia retention. Time studies indicate that the effect persists for as long as 48 days after injection. Preliminary results indicate that the injected ammonia or the resulting accumulation of nitrite-nitrogen may be the factors responsible for killing the organisms.

D. Patulin in Decomposing Residues

During the year, studies continued at Lincoln, Nebraska, on the antibiotic patulin, the fungus that produces it, and its importance in depressing wheat yields under stubble-mulch systems. Soil samples were collected from fields at Lincoln and Dalton, Nebraska; Sidney, Montana; Mandan, North Dakota; and from several Colorado locations to determine Penicillium urticae B numbers. When crop residues were left on the soil surface, an increase in numbers of P. urticae B was found at all locations. Cool and/or fluctuating soil temperature (which is characteristic of conditions under some mulched fields) plus adequate residue, stimulate P. urticae B. numbers in the soil. Populations sometimes exceed 50 percent of total fungal population. However, under laboratory conditions, patulin was decomposed in 4 days. Field applications of patulin to wheat early after planting and in the spring

during active growth and elongation stages reduced plant yields by inhibiting germination, killing, reducing plant vigor, decreasing final seed weight, and total yield. However, in a field study at North Platte, Nebraska, on which patulin was applied in the fall, the material acted as a stimulant. Data collected to date suggest that additional well instrumented field and laboratory studies are needed before the influence of this toxin on the wheat plant can be really determined.

E. Microbes from Cattle Feedlots

Concentrations of livestock into small areas and the associated accumulation of animal residues have raised many questions about pollution from these facilities. Laboratory studies conducted at Fort Collins, Colorado, on soils from and under various feedlots showed that there is a rapid die-off of the coliform population in feedlot soils at the usual animal stocking rates and the concomitant high ammonia concentrations arising from the urea excreted in the urine. The relatively short half-life of the coliform populations excreted in the feces, together with the failure to find any appreciable downward movement of the coliforms in the soil profile, indicates little danger of ground water contamination with coliforms of feedlot origin. Ammonia concentrations found in about half the total number of commercial feedlots examined were of the order of 1,000 p.p.m., a level shown to be strongly bactericidal to the nitrifying bacteria. The nitrification studies completed strongly suggest that feedlot stocking rates and corral management practices can be controlled to inhibit nitrification in feedlots, and thereby reduce nitrate enrichment of ground water. Evidence indicates that energy-rich organic materials in animal excreta are leached into and through the soil profile under feedlots, thereby causing greater growth of the indigenous soil bacteria in the deeper profile and in the ground water.

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SOIL-WATER CONSERVATION FOR EFFICIENT USE OF PRECIPITATION ON CROP AND RANGE LANDS

(RPA 105 - Conservation and Efficient Use of Water for Agriculture)

USDA And Cooperative Program

Location of Intramural Work	Scientist Man-Years FY 1968
Virginia	1.0
Georgia	0.6
Mississippi	2.2
Illinois	1.3
Iowa	0.3
Minnesota	1.6
Wisconsin	1.0
Colorado	1.8
Montana	0.7
Nebraska	0.1
North Dakota	1.8
Wyoming	0.3
Texas	2.6
Idaho	0.9
Oregon	0.4
California	1.0
Total	17.6

Intramural program is supplemented by extramural support representing P.L.-480 funds in 1 country representing $17,546 U.S. dollars' equivalent.

Problems and Objectives

Recurring droughts remain one of the biggest problems that plague agriculture in all parts of the United States. Each year, some parts of the country suffer from various degrees of drought. Many farmers were forced to discontinue their operations in the Northeast during the 3-year drought in 1964 - 1966. Weather records in the Plains show that precipitation reduces yields in over half of the years. When moisture data and crop yields are compared, it becomes apparent that during most drought years, 1 or 2 inches of water will make the difference between a crop and a failure. The challenge then is to develop systems that will increase small amounts of water entering the profile or reduce the amounts lost by evaporation.

The objectives of this work are to develop systems for increasing infiltration, reducing evaporation and chemically or genetically manipulating plant morphology to more efficiently use the water in the soil.

Progress - USDA and Cooperative Programs

A. Factors Influencing Infiltration

In a continuing search for methods to increase water storage during the fallow period in the Great Plains, the condition of the surface soil when rains occur is being evaluated. Included in these studies are fallow systems which do not keep the land free of weeds as is commonly done on fallow land.

At Bushland, Texas, following a 6-month drought, 3.6 inches of rain occurred in the 6-day period from April 8-13, 1967. Storage of water in the soil profile from these rains varied with the surface condition of summer fallowed land. Delayed fallow (stubble not disturbed until spring weeds start) and volunteer wheat plots stored 2.43 and 2.00 inches of water respectively, whereas the early fallow treatment kept free of all plant growth stored only 0.14 inch of water from these rains. The increased water storage under the delayed fallow and volunteer wheat plots was attributed to the cracked condition of the surface soil on these treatments. This finding illustrates the importance of the soil surface condition in water infiltration and storage.

As runoff proceeds downslope, there is an opportunity for additional water to infiltrate the soil. Thus, more water may be available for plant growth at lower elevations of long slopes than at higher elevations. At Bushland, Texas, this hypothesis was tested in 1967. Differences in soil water storage of as much as 5.7 inches in the 6-foot profile were found from the lower to the upper end of a 1 percent slope

1900 feet long. These data are of considerable significance because they suggest that slope effects can be of major importance on lands with very little slope.

The response of soybeans and corn to soil surface roughness, mulch, and row spacing has been investigated on Blackland soils over a 3-year period at State College, Mississippi. More rainfall was captured by a rough soil surface but the 3-year average yields were not significantly different for rough and smooth soil surfaces. In one of three years, corn grain yield was significantly increased by the imposed roughness. Grain yield was consistently increased 5 to 10 percent by straw/mulch application to the soil surface.

Basic studies concerned with attempting to predict the flow of water into the soil and down the slope on rough terraces have continued during the year. At Urbana, Illinois, analysis of flow in a sloping slab, using an analogue technique, has shown that even with rainfall rates less than enough to saturate a soil mass, interflow can still contribute substantially to runoff. Hydrologic analysis must therefore account for the underground and return flow for accurate assessment of a watershed.

At Madison, Wisconsin, considerable progress has been made in the derivation and solution of theoretical flow equations. A study on the kinematics of soil water showed that streamlines, path lines, and streak lines are useful in characterizing two- and three-dimensional motion of soil water and of substances dissolved in soil water. In isotropic, partially saturated soils the direction of water movement is normal to surfaces of equal total head; therefore, the flow direction at any point may be inferred from measurements of the total head at a sufficient number of points. The apparent ambiguous nature of the concept of stress in porous media is merely a consequence of considering just some rather than all of the forces acting upon the solid phase. A similarity analysis of diffusion and dispersion in porous media has been formulated. The analysis suggests numerous relationships that may be tested experimentally. Tests involving oscillatory mean motion gave results in agreement with the similarity analysis. In a given porous medium, the dispersion is a function not only of the average velocity but also of the amplitude of the average displacement depth.

At Ames, Iowa, a computer program was developed to study infiltration into a soil surface in which the hydraulic conductivity was reduced with time due to rainfall impact. Water infiltration into the soil was conditioned not only by the conductivity of the surface but also by the character of the underlying soil. In agreement with other studies, the shape of the capillary conductivity-suction curve in the underlying soil as suctions between 0 and 150 millibars was important in determining the suction gradient through the surface layer.

The phenomena associated with describing infiltration on field sites using accepted flow theory for porous media has been under study at Watkinsville, Georgia. The water content-suction relationship in the range from 25 millibars to 2 millibars of undisturbed samples of Cecil fine sandy loam subsoil horizons has been shown to be significantly different from that of sieved samples. This difference has also been suggested by the Ap horizon data, particularly at the lowest soil water suctions. In the low water suction range, the differential water capacity determined for the two types of samples was significantly different. This confirms the necessity for using samples having field structure for all water flow studies which are to be applied to field sites. The reduced range in water content of undisturbed subsoil samples over the suction range less than 2 bars, in contrast to the sieved samples, emphasizes a marked water capacity difference as well. Soil water diffusivity measurements of Cecil sandy loam major soil horizons have shown the subsoil horizon to be higher on the average than the surface soil horizon in the less than 1-bar range.

B. Management of Winter Precipitation

Because as much as 25 percent of the moisture occurs as winter precipitation in the Northern Plains, studies on methods of capturing the high percentage lost by runoff from frozen soils continue. Exploratory fall tillage studies at Sidney, Montana, under the snow cover conditions of the winter of 1966-1967 on a post spring wheat harvest dryland site and a native range site indicate a potential exists to increase soil water storage from spring snowmelt. Fall subtilled dryland stored 4.27 inches of water in a 5-foot profile compared with 3.09 inches on nontilled land. The same tillage treatment on native rangeland resulted in 4.3 inches of water storage in 4 feet of soil compared with 3.2 inches on nontilled land.

A study also at Sidney shows that soil on which a combination of mulching, furrowing and the formation of holes filled with straw at the bottom of the furrows have a maximum infiltration capacity in excess of 4.9 inches per hour. This quantity was double the maximum rate on conventional fallow.

Deposition of snow at Akron, Colorado, by the standard snow fence with every third slat removed (28 percent wood) was greater than with the other snow fences tested. Results in 1967 are similar to the 3 previous years with deposition to 60 feet leeward of the fence. For 1963-1967, snow fences 24-inches high have deposited 71 percent as much snow as the 48-inch high fence. These data suggest that crop barriers can be effective in capturing snow.

The water content of the soil in the fall and height of stubble has had an effect on snowpack runoff from wheat land at Mandan, North Dakota. Snowpack runoff was 98 percent from field plots which were wet in the fall before freezing, and only 65 percent from plots which were dry in the fall before freezing. Snow melted faster on plots with taller standing stubble. Height of the standing stubble had more effect on the beginning and duration of snowpack runoff than did soil-water level in the fall before freezing.

C. Factors Affecting the Loss of Water by Evaporation

In the Great Plains only 1 inch out of every 5 that fall on fallowed land is stored for the following crop. This inefficient moisture conservation practice has caused scientists to continually look for methods of reducing evaporation losses. Studies at Fort Collins, Colorado, showed that the evaporation of water from the soil was greatly affected by the method of wetting. Flooded soils had evaporation rates up to 50 percent higher the first 10 days after wetting than did soils wetted slowly by rainfall. The differences in evaporation were caused by differences in depth of wetting, in water content in the upper surface layers (caused by hysteresis), and in crust formation.

Evaporation reduction by the addition of a gravel mulch may cause significant increase in ground water recharge according to the results of studies at Fort Collins, Colorado, in 1966 and 1967. Of 23 inches of precipitation received from September 1966 to September 1967, evaporation from a soil covered with 5 cm. of pea gravel was 4 inches, with 2 cm. of pea gravel, it was 8 inches, and with bare soil, it was 19 inches. On large areas, this water saved might contribute eventually to ground water recharge.

Soils like the Houston black clay develop tremendous cracks upon drying. Scientists for sometime have speculated that water losses from these cracks might be sizeable. Evaporation from a simulated soil shrinkage crack has been evaluated at Temple, Texas, under controlled temperature, wind movement, and vapor pressure conditions. Evaporation increased as either wind velocity, crack depth, or crack width increased. Thus, any object at the soil surface which reduces wind speed across a shrinkage crack will decrease evaporation. In the field, this could be accomplished by closer plant or row spacings and by surface residues such as trash or clod mulches.

Frequently, reduced yields associated with subsoils are attributed to a lack of nutrients. However, field observations made in Virginia suggested that these reduced crop yields might be associated with soil moisture. Studies on a limestone soil at Blacksburg, Virginia, indicated that available soil water was the principal soil factor determining plant growth and corn yields on well managed subsoil. Corn

production on subsoil with adequate fertilizer and irrigation was comparable to that on similarly managed plots from which the topsoil had not been removed. On nonirrigated but well-fertilized plots, corn yields averaged 76 bushels on subsoil vs. 96 bushels on topsoil. A straw mulch on subsoil plots conserved water and increased yields to 127 bushels. Irrigation in addition to the mulch increased yields to 148 bushels, which was the same as on topsoil with irrigation. Rainfall for the season was below normal, especially in June and July when total precipitation for the 2-month period was 5.1 inches, 4.0 inches below normal.

In a P. L.-480 study in Israel concerned with determining how losses of water from the soil profile by evaporation might be reduced, well aggregated soil tended to lose more water by evaporation immediately after rainfall, but a higher percentage found its way deep into the profile than on the poorly aggregated soil. Future studies will be concerned with attempting to reduce the water lost by evaporation and still obtain redistribution deep in the profile.

D. Factors Influencing the Use of Water by Crops

1. Surface color. Soil surface color influenced soil-plant-water relations at Fort Collins, Colorado. Water use by corn averaged 16 percent more when adjacent to white surfaces than when adjacent to black surfaces from August 1 to September 11. Changing of the color between the rows at midseason resulted in a general increase in water use when the change was from black to white surfaces. Moreover, the transpiration of water from plants grown adjacent to white surfaces early in the year either increased or did not change when the plants were adjacent to black surfaces the latter part of the year. Corn yields were higher on black plots than white plots, while sugar beet yields were from 29 to 35 percent higher on the white plots than on the black plots.

Corn yields in 1967 at Fort Collins, Colorado, were increased from 73 to 87 bushels per acre by the addition of a 1-inch coal mulch to the soil surface compared with a bare surface. This increase was attributed largely to reduced evaporation from the soil surface with the addition of the coal mulch.

2. Moisture use on grassland. The successful seeding of grass species on dryland soils is extremely low. In a continuing study concerned with determining which factors are responsible for the low success, a number of measurements has been made at Kimberly, Idaho. Multiple regression analysis of seven selected chemical and physical site variables accounted for 52.8 percent of the variability in plant frequency of crested wheat grass on southeastern Oregon rangelands. The independent variables in the order of their importance were soil organic matter content, soil pH, water soluble K content of the soil, potential solar radiation at the site,

soil bulk density, available water capacity and potential yield increase upon fertilization. Precipitation is undoubtedly the major variable in determining reseeding success. However, since precipitation varies and is not easily controlled, these seven factors are important criteria for reseeding site selection.

About 60 percent of the production of native shortgrass range (Pullman silty clay loam) at Bushland, Texas, were lost by delaying harvest from July to November when the grass was dormant for most of the July-November period. Ranchers who save their shortgrass ranges for winter grazing may take a severe reduction in dry matter plus any deterioration in quality that occurs when dry forage is exposed to the weather.

E. Influence of Fertilizer on the Efficiency of Water Use

In studies at Riverside, California, a hydraulic lysimeter was used to determine the effect of barley leaf area on evapotranspiration. Nitrogen applied at the rate of 45 kg. per ha. shortly after barley emergence increased the green leaf area 37 percent at the boot stage and by 100 percent at the milk stage. With the same seasonal pattern of water, additions higher average daily evapotranspiration was associated with greater leaf area. An increase in total ET from tillering to maturity of 1.5 inches was recorded for the nitrogen fertilized barley. From heading to maturity, relative turgidity of barley leaves measured at noon was 10 percent less where leaf area was greatest. The nitrogen treatment increased straw yield 40 percent and resulted in greater culm and head densities but only slightly increased the barley grain yield. These data verify that nitrogen may increase water use by increasing transpiring left area which in turn may result in yield reductions of grain during years of short water supply.

Efforts to increase water availability for dryland crops at Riverside, California, resulted in increases in barley yields and water-use efficiency from the use of runoff water. Increased water availability, obtained by impounding runoff from waterproofed areas equal in size to cropped areas, increased barley yields to a level comparable to that obtained after fallow in a fallow-crop system.

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ROOT GROWTH AND ACTIVITY AS INFLUENCED BY SOIL PROPERTIES AND ENVIRONMENT

(RPA 102 - Soil Structure; and Soil, Plant, Water Nutrient Relationships)

USDA and Cooperative Program

Location of Intramural Work	Scientist Man-Years FY 1968
Maryland (Beltsville)	3.8
Alabama	3.6
South Carolina	3.5
Illinois	1.0
Montana	0.6
North Dakota	0.6
Texas	1.5
Idaho	0.3
Oregon	0.3
Washington	0.2
Nevada	1.0
Total	16.4

Intramural program is supplemented by extramural support representing (a) 0.5 SMY's at State Agricultural Experiment Stations, and (b) P.L.-480 funds in 1 country representing $6,669 U.S. dollars' equivalent.

Problems and Objectives

Plants depend on their root system to absorb the water and plant nutrients required in growth processes. Root growth of developing plants proceeds according to a genetic pattern but is strongly modified by environmental conditions. Therefore, it is not uncommon to find a naturally deep-rooted plant unable to extend its roots effectively into the soil because of an unfavorable chemical, physical, or biological condition encountered there. Knowledge of the specific environmental factors that control root development and function is meager indeed. Some chemical soil characteristics are known to affect root growth, including acidity, and nutrient toxicities and deficiencies. Chemically, the most unfavorable conditions probably prevail in the highly leached tropical soils. Physical soil properties can also impede root growth. Unfavorable physical conditions, such as high strength, compact layers, and zones of low air transmission are commonly found in agriculturally important soils. Less is known about biological soil characteristics that might inhibit root growth. Limited research has been directed toward the identification of possible beneficial and harmful effects of micro-organisms associated with plant roots.

The purpose of these studies is to isolate and define the factor in soils that limit root development and develop soil and water management systems that will create a soil environment conducive to good root growth. Criteria such as soil strength, bulk density, and oxygen level that can be used to define soil compaction and to predict the degree of root performance and development will be developed. Also, the elements in an acid soil that are deficient or toxic to plant roots will be identified. The plant properties that are associated with differential tolerance to various ions, such as aluminum and other elements, will also be identified. After these factors are understood, management systems will be developed that will obtain the desirable environment for plant roots.

Progress - USDA and Cooperative Programs

A. Influence of Varieties on Aluminum Tolerance

Differential aluminum tolerance studies of various crop roots, reported in the past 3 years, have yielded results that are of importance in acid soil areas. During the past year, detailed studies of the mechanics involved in the differential tolerance of various crops have been evaluated at Beltsville.

Results show that aluminum interferes to different degrees in the uptake and utilization of calcium by different soybean varieties. This is associated with greater susceptibility to a petiole collapse symptom, which in turn was shown to be related to a lower calcium concentration in the leaves and petioles. Studies indicated that the calcium deficiency observed was aluminum induced.

Because many acid soils contain high levels of manganese, screening of plant species and varieties for tolerance to acid soil conditions has been enlarged to include manganese. Manganese-tolerant cotton varieties have been identified. Many soils of the Eastern cotton belt are potentially manganese toxic. The importance of breeding manganese-tolerant varieties is suggested.

Drought damage by shallow root growth is a common problem in the Southeast. As a result of poor root development in the subsoil, plants are unable to make effective use of profile stored moisture and nutrients. In order to determine if plant varieties within a species differ in their tolerance to acid soils, several varieties of wheat and barley were tested on several soils in South Carolina. Results showed that varieties differed widely in their tolerance. The differences in most cases were attributed to Al-induced Ca deficiency. Toxicities occurred in the Norfolk and Goldsboro soils, but there was no evidence of toxicities in the Marlboro soil. These data are of great value in developing cropping systems for some of the problem soils of the Southeast.

B. Influence of Soil Chemical Properties on Root Growth

Growth chamber studies at Auburn, Alabama, have consistently showed that both calcium deficiency and aluminum toxicity are important contributors to the shallow root systems in the humid-temperate and humid-tropic regions. During the last year, results from a study concerned with the influence of aluminum on uptake of ions showed that as the concentration of aluminum increased, the number of ions taken up by the plant decreased. The first measurable evidence of aluminum toxicity was a reduction in the uptake of Ca. Peanut roots subjected to aluminum treatment sufficient to kill cotton roots showed no decrease in ion or water uptake.

During the year, three Alabama soils and three soils from Puerto Rico, reported by the Soil Conservation Service Laboratories as being very low in calcium and other bases, were studied in glass-fronted boxes, using cotton as the indicator crop. All soils responded to calcium treatment. These data show that the highly weathered soils in Alabama are chemically and mineralogically indistinguishable from those in Puerto Rico. There is also a close association with the large acreages of poor producing soils in Brazil that are low in calcium. All of these soils support little plant growth without calcium treatments.

C. Influence of Soil Physical Properties on Root Growth

In an attempt to gain a better understanding on the influence of physical properties on root development, studies concerned with relating soil strength to root growth have continued at Auburn, Alabama. During the past year, the yield of cotton was significantly increased by chiseling immediately under the cotton row. In this case, the cone index penetrometer resistance was about 600 p.s.i. on the check plots when near the field capacity soil-water

content. However, yields of cotton, peanuts, and corn were not significantly affected by deep tillage at five other locations in Alabama.

Because of the variability within a crop susceptible to compact horizon, the root pressure at which various plants are damaged was examined. Measurements show wide variation from plant to plant within a variety. Root growth pressures within species of cotton, peas, and peanut plants varied widely also. These data offer an excellent opportunity to select or breed plants that have the ability to penetrate high strength soil layers.

In order to gain a better understanding of the relationship between bulk density and root development, the characteristic strength, bulk density, and soil-water relationships of A_1-, A_2-, and B-horizon material from a Norfolk loamy sand and mixtures thereof were determined in the laboratory at Florence, South Carolina. The strength of A_1-soil material exceeded the A_2 soil at similar bulk density and water-suction levels, although the strength of the A_2 increased more rapidly than the A_1 with increased water suction. Mixing B-horizon with A-horizon materials increased the strength somewhat above the A alone at low water suctions and decreased the strength at higher water suctions, e.g., 2 bars.

Because power is now available for mixing soil profiles to a depth of 2 or 3 feet, several studies have been initiated to evaluate the influence of soil profile mixing on rooting depth and crop response.

At Florence, South Carolina, a Norfolk loamy soil was mixed to determine the effect of this profile modification upon the growth and yield of cotton and soybeans. Preliminary data show that by mixing, root penetration of both crops is increased very significantly and that water use occurs to the full depth of mixing. Although valid cotton seed and fiber yields have not yet been obtained, total dry matter production appears to increase with tillage depth.

Four years after a Houston Black clay, a soil with very undesirable physical characteristics was deep tilled, the structural stability was evaluated in the laboratory at Temple, Texas. Structural stability of modified heavy clay soils as evidenced by reduced bulk density, improved aeration, and improved water transmission characteristics suggest that deep tillage may have practical economic implications. With the benefits likely persisting for more than 4 years, it should be economically feasible to deep plow once in 5 years for root rot control and increased production.

Under limited moisture (preirrigation only), profile modification (profile mixing to a depth of 5 feet) of Pullman silty clay loam has consistently increased grain sorghum yields. Increased yields were attributed to increased rooting depth which resulted in deeper moisture extraction. Under full irrigation and adequate fertilization, profile modification had little effect on grain sorghum yields.

Shallow crop root caused by poor drainage and high salt and sodium contents is a problem in the western United States. The use of the platinum microelectrode technique for measuring aeration status of saline and sodic soils was evaluated at Reno, Nevada. Microelectrodes with tips touching a pure salt solution were used to simulate unsaturated soils at various salt and sodium levels. The results indicate that salt concentrations in the soil solution will have little influence on oxygen diffusion rate (ODR) measurements in soil if proper corrections are made for potential losses in the measuring system and if monovalent ions do not compose more than 80 percent of the total cation population.

Each year, large acreages of crops like cotton, sugar beets, and beans are reseeded because heavy crusts form on the soil surface after spring rains or irrigation. For example, bean seedlings have difficulty emerging through crusted soils in southern Idaho. During the year, eleven seed orientations were studied and found to significantly influence the emergence of the bean seedling. The flat orientation (1 bean seed every 4 inches) and the multiple or "buddy" plantings (2 bean seeds every 8 inches) resulted in better and more rapid emergence. The earlier emergence of those in multiple plants was reflected in earlier blooming. Planter modifications are presently being made in order to compare preferred orientations with standard planting methods in the field.

Deep plowing has consistently improved the productivity of "slick spots" (soil high in exchangeable sodium) in the Northwest. In order to gain information on these important soils, a lysimeter study conducted at Twin Falls, Idaho, to evaluate soil profile mixing to simulate deep plowing showed that several kinds of saline-sodic slick-spot soils can be made productive by deep mixing and leaching. Three saline-sodic soils, representing severe slick spots, were essentially reclaimed by the mixing and leaching. Three saline-sodic soils, representing slick-spot soils with moderately thick clay loam and clay B horizons overlying coarser textured, calcareous soil material, were substantially improved chemically and made productive by deep mixing and moderate leaching in a single cropping season. These data are of real interest to operators of thousands of acres of "slick-spot" soils in the Northwest.

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SOIL-PLANT-METEOROLOGICAL INTERACTIONS AS THEY AFFECT ENERGY CONVERSION INTO USABLE PLANT MATERIAL

(RPA 105 - Conservation and Efficient Use of Water for Agriculture)

USDA and Cooperative Program

Location of Intramural Work	Scientist Man-Years FY 1968
New York	2.0
Georgia	3.3
Mississippi	1.0
Illinois	3.2
Minnesota	1.0
Colorado	1.4
Montana	1.0
Nebraska	0.9
Texas	3.0
Idaho	0.3
Total	17.1

Intramural program is supplemented by extramural support representing (a) 0.0 SMY's at State Agricultural Experiment Stations, and (b) P.L.-480 funds in two countries, representing $40,406 U.S. dollars' equivalent.

Problems and Objectives

Since 1950, we have made tremendous strides in the art and science of producing crops. With modern techniques for controlling pests, improved plant breeds and increased use of fertilizer crop yields have been substantially increased. However, despite these increases, the efficiency of energy use (photosynthesis efficiency) is still only 2 to 2.5 percent. This means that only a small part of the energy reaching the soil surface is put to use. Even though there are no indications of a major breakthrough for improving the basic photosynthetic process, there are indications that the efficiency can be improved by more efficiently using the soil water, changing the shape of the plant so that it will utilize more light, and by making better utilization of the growing season.

The objectives of this work are to identify the climatic factors responsible for crop production, determine the plant shapes and geometry for the most efficient energy capture, and develop soil and management systems that will increase the energy conversion by the plant.

Progress - USDA and Cooperative Programs

A. Influence of Energy Balance on Water Loss by Evaporation

During the past 5 years, the interest in predicting crop response to the total environment has increased many-fold. In order to make these predictions, the relationship between evaporation losses and microclimatic conditions needs to be known.

The magnitude of water loss by evaporation during and immediately following furrow irrigation of a row crop having a limited canopy generally is not known because such losses are difficult to measure. A modified energy balance technique was used to determine the evaporative loss of water from a bean crop immediately following an irrigation at Twin Falls, Idaho. The results indicated that the ratio of latent heat flux (evaporation) to net radiation decreased rapidly as the wet soil surface dried when there was a partial crop canopy. Evaporation losses decreased by 50 percent 5 days after irrigation. These studies also indicated that with moderately dry soil and little plant cover, the errors of measurement can cause large errors in the determination of latent heat.

At Temple, Texas, measurements of net radiation and grain sorghum water use under dryland conditions showed that the magnitude of daily sensible heat flux exceeded the magnitude of daily net radiation during the maturing stage of plant growth when soil water was less available. Net radiation and water use were approximately equal during the first

part of the season when plants were rapidly developing their leaf system. Evaporation from soil shrinkage cracks in the Houston Black clay was found to be the major source of evaporative flux from a bare soil when the soil surface was extremely dry. The loss was influenced by evaporative demand and windspeed.

Rate of water use by grain sorghum as measured in a lysimeter was strongly influenced by (1) stage of plant growth, (2) depth integrated soil water potential, and (3) the microclimate. Daily water use followed the general trend of an estimated potential water use curve through the season except for lower rates of water use caused by the lack of available soil water. Daily departures from the general water use trend were mainly influenced by degree of cloudiness.

Results from continuing studies at Akron, Colorado, show that evapotranspiration is highly dependent on the type of crop. Over a 3-year period, the ratio of ET to E_{pan} (evaporation from a free water surface) for oats was as high as 2.0, while the value for native grass was 1. Sudangrass was similar to native grass, but winter wheat, millet, and sorghum showed intermediate values to those of native grass and oats. Limited measurements of net radiation and soil heat flow indicate very few periods when part of the energy from net radiation over native grass was not being used to heat up the air. In contrast over oats, a third of the energy used for evapotranspiration was extracted from the air during one 20-day period.

One additional finding in this study that has considerable significance is that by eliminating deep percolation below 90 cm. with a metal barrier, sorghum yields were doubled with only a 50-percent increase in evapotranspiration. Similar results were obtained in 1966. These data, preliminary as they are, suggest that the loss of water by deep percolation under dryland conditions can have a significant influence on crop yield.

B. Influence of Crop Canopy on Photosynthesis

Studies have continued at State College, Mississippi, to determine the relationship between light interception, net photosynthesis, and geometric features of cotton leaves and canopies. Seasonal totals of the potential net carbohydrate production by four cotton stands, as projected from data on light interception and photosynthetic efficiency, show that yields should be on the order of 14 to 17 bales per acre. Our inability to produce much more than one-eighth of this potential points to a serious need for the development of means and control methods for directing the translocation of photosynthate into fruit.

At Urbana, Illinois, experiments have continued on the factors influencing soybean photosynthesis. Studies on individual leaves in canopies showed that both respiration and photosynthesis declined with depth into the canopy. The older leaves were able to operate more efficiently if placed in full sunlight, but did not obtain the efficiency of leaves that were continuously in full sunlight. It was found that excision of the leaves from the plant produced a reduction in photosynthesis compared with leaves left on the plant.

Photosynthetic efficiency of a large number of soybean varieties has been tested. The range of values obtained varied from 32 to 65 milligram CO_2/diameter^2/hour. Values obtained in field canopies averaged 10-15 mgm/dm^2/hour. These data indicate that there is a real opportunity to develop soil and water management systems for the promising soybean varieties.

Because of the need for accurate methods of predicting light in crop canopies, a series of field studies has been conducted at Ithaca, New York. A modified deWit model for predicting light distribution in crop canopies was tested in corn and found unsatisfactory. Model improvements are now being tested. Power spectra of CO_2 fluctuations above a corn crop before and after a killing frost showed that after frost, fluctuations with periods between 6 and 30 seconds disappeared and fluctuations with periods of about 5 seconds remained. Studies to develop a "direct" or eddy correlation technique for measuring CO_2 flux intensity in the field will continue.

Because the microclimate is fairly well understood in crop canopies and so poorly understood in vegetation above 3 feet (forests, for example), the transfer process for carbon dioxide, water vapor, heat momentum, and radiation were studied in a forest canopy at Ithaca, New York, and in Costa Rico. Preliminary results from a Japanese larch plantation and a Costa Rican rain forest indicate the need for making more precise measurements of these variables. It does appear that with some modification methods used for field crops can be used for these studies. Wind acceleration in a Costa Rican jungle has again demonstrated that wind acceleration or "blow through" below the crown canopy prevents the use of the present CO_2 flux model.

C. Influence of Stomata Opening on Vapor Diffusion

Since the major quantity of water evaporated from growing plants must pass through the leaf stomata by vapor diffusion, the diffusion resistance associated with this vapor transport is an important quantity in plant-water problems. At Watkinsville, Georgia, the diurnal pattern of the diffusion resistance of cotton leaves has been established when the plants are grown under a set of "standard" conditions. The effect of varying carbon dioxide concentrations of the aerial environment and osmotic potential of the nutrient solution in which the plant's roots

were immersed has been evaluated. The diffusion resistance of cotton leaves increased as the CO_2 concentration in the atmosphere increased from 100 to 650 p.p.m. No further increase occurred as the CO_2 concentration was increased to 1000 p.p.m.

In a continuing search for a better understanding of the processes involved in the operation of the guard cell and control of water loss by plants, researchers at Watkinsville have found that the enzymes B-amylase produces an effective block to starch storage by epidermal cells. A laboratory method has been developed for identifying and quantitatively determining small amounts of organic compounds in extracts of epidermal tissue.

At Ithaca, New York, stomatal behavior in the field has been continued. A relationship between diffusion resistance from corn leaves and light intensity under conditions of adequate moisture has been established. The variability of light intensity on leaves as a result of intermittent exposure to direct sunlight caused variability in leaf resistence measurements. These data, though preliminary, indicate that progress is being made on developing instruments that will be valuable in predicting stomatal behavior.

D. Diurnal Growth of Soybeans

At Bushland, Texas, diurnal growth rate curve for soybeans showed that most growth occurred during the last quarter of the day, with the maximum around 6 to 8 p.m. Previous growth studies of sorghum and corn showed the maximum growth between 6 and 8 p.m., and a minimum growth rate at about 6 a.m.

E. Protection of Crops from Freezing

Untimely freezes cause considerable economic losses to fruit and vegetable producers in the Lower Rio Grande Valley. During the past year, freeze prevention studies with citrus and vegetables have been started at Weslaco, Texas. A fire-fighting foam was evaluated for protection of a freeze susceptible mature sweet pepper crop on a radiation frost night with temperatures near 0° C. An increase in leaf temperature of 8° C. occurred immediately upon application of the foam and maintained leaf temperatures about 4° C. warmer than adjacent untreated peppers for the first 4 hours after initial foaming and about 1° C. warmer for the next 6 hours. Soil temperature at a 2 cm. depth stopped dropping as soon as the foam was applied and by the next morning was 4° C. warmer than the nonfoamed plot. Although additional data are needed before recommendations can be developed, preliminary results are encouraging.

Also at Weslaco, the environment in a citrus grove during cold conditions was evaluated by measuring key parameters during three different nearly calm nights during which near or below freezing

temperatures occurred. The rate of air and tree temperature decrease varied considerably on the different nights. The calculated net radiation value for a tree gave an indication of the rate of temperature decrease expected. Key components in the calculated tree net radiation were incoming long wave radiation and radiation from the soil which helped add energy to the tree. When incoming long wave radiation was less than 0.32 cal $cm.^{-2}$ $min.^{-1}$, rapid cooling occurred. Petroleum coke under-the-tree heater blocks were used to study heating effects. The heated tree's internal foliage was generally 1.0 to 1.5° C. warmer than the internal foliage of unheated trees. The outside leaves increased less in temperature than leaves within the tree canopy.

These data, inconclusive as they are, yield information that will be helpful in predicting when freezing will occur and will be useful in reducing the damage to the crop when freezing conditions occur.

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INTEGRATION OF MANAGEMENT SYSTEMS
FOR MORE EFFICIENT USE OF CROP AND RANGE LANDS

(RPA 102 - Soil Structure; and Soil,
Plant Water Nutrient Relationships

USDA and Cooperative Program

Location of Intramural Work	Scientist Man-Years FY 1968
Pennsylvania	1.0
Georgia	1.8
Puerto Rico	0.2
Minnesota	1.0
Colorado	1.0
Montana	1.7
North Dakota	1.5
South Dakota	1.0
Wyoming	0.5
Texas	1.5
Washington	2.6
Total	13.8

Problems and Objectives

Most of our laboratories and field locations have conducted research that has yielded data that has later led to the development of principles of various types. In most cases, these principles have never been combined with other systems to construct soil and water management systems that can be applied to the land by the farmer or rancher. Although a great deal has been said about system analysis, little progress has been made at applying this approach to a farmer's or rancher's unit.

The purpose of these studies is to determine the manner in which cropping systems, cultural practices, water control, and fertilizer methods and combinations thereof can be fitted together for maximum agricultural production and optimum conservation, soil and water resources. The investigations will include developing methods for integrating soil, water, and fertilizer practices into systems for the most efficient utilization of crop and range lands as influenced by soil type and land resource area.

Progress - USDA and Cooperative Programs

A. Cultural Practices for Steep Slopes

The efficient utilization of steep slopes depends to a large degree on developing the best system for these areas. Preliminary data collected on plots in West Virginia in 1966 showed that forage production on north-facing slopes was as much as seven times greater than on the south-facing slope.

Additional data collected in 1967 on these slopes revealed that soil temperature, soil moisture, water-use efficiency, responses to nitrogen fertilizer, production of different pasture species, and seasonal distribution of yield are all affected by slope orientation. Yields of well fertilized Kentucky bluegrass were about 6000 pounds per acre on the northern exposure as compared with less than 3000 pounds on the southern exposure. Responses to nitrogen fertilizer were much greater on the northern slope. Midland Bermudagrass, on the other hand, produced 6800 pounds on the northern exposure and 10,000 pounds on the southern exposure. Total production of tall fescue, crownvetch, and birdsfoot trefoil was little affected by direction of slope. These data suggest that if efficient use is to be made of the steep lands in Appalachia, management systems will have to be developed for each slope condition.

Because soil erosion is severe on these slopes, conventional tillage systems for cultivated crops cannot be used without damaging the land. In tillage studies, yields of corn grain and silage planted directly in sods of each of five grass species at two locations in West Virginia were higher than on plots with conventional tillage, and little or no soil was lost by erosion. Bromegrass sods showed particular promise for this practice. Bromegrass treated with herbicide last year made excellent recovery following the corn

crop, and a good hay crop was obtained this spring. Methods to control erosion in intensively managed coffee growing in full sunlight on steep slopes in the mountain region of Puerto Rico have been evaluated. Data from 3 bearing years show that coffee grown with grass strips between the rows with coffee mulch under the trees yields consistently higher than coffee under clean cultivation, and coffee with grass strips and clean cultivation under the trees. Mulching with grass or black plastic under the trees did not significantly increase the yield of strip-cultivated coffee. These data show that strip cultivation can be used to control erosion in intensively managed coffee plantations on steep slopes without affecting coffee yields.

B. Management Systems for Lower Rio Grande Valley

Cotton production in the Lower Rio Grande Valley is low compared with comparable areas of similar latitude in Mississippi and California. Generally, cold soil conditions restrict planting until late February and a mandatory stalk destruction deadline of September 1 for pink bollworm control shortens the blooming and fruiting period compared with other high producing areas. To test the effect of extending the growing season by earlier planting, cotton started under clear polyethylene plastic tents (1-foot high) was compared with cotton not covered with plastic. Thirty-five days from planting, the plastic covered plants were 15.7 cm. tall compared with 8.0 cm. for the noncovered plants. Fiber and seed yields reflected the early response. Future studies will be concerned with extending the growing season.

Another factor limiting cotton production in the Lower Rio Grande Valley is restricted root development, particularly on the heavy clay soils. To overcome this limitation, profile modification by trenching 4 inches wide and 24 inches deep under the plant row was attempted. The trenches were backfilled wholly or partially with loose soil, perlite, or sand. Any treatment that included trenching resulted in a yield increase compared with conventional tillage. On the average, the trench treatments yielded about 2/3 bale per acre more than the nontrenched treatments.

The information obtained from these two studies is encouraging because it now appears that it should be possible to put together a management system which will increase crop yields in this important agricultural area.

C. Management Systems for Increasing Soil Water

In most of the midwest States, crop yields are reduced by a shortage of water. Results from several studies concerned with increasing the stored water have shown that in western Minnesota and eastern South Dakota, dormant season (September 15 to May 15) recharge of soil water was negatively related to total soil water in the profile on September 15. Fall recharge (September 15 to November 15) was closely related to precipitation received during the period. During this period, about 1 inch of precipitation was

required to initiate fall recharge. If the surface soil is wet at the time the soil freezes in the fall, all of the winter moisture accumulating as snow will be lost as runoff. If the soil is dry at the time the soil freezes, storage from winter precipitation will be highest on standing corn stalks followed by alfalfa and fall-plowed land.

At Bushland, Texas, available soil water at seeding time in the fall amounted to 5.17 inches for the wheat-fallow-wheat rotation, 3.16 inches for the wheat-sorghum-fallow rotation, and 2.30 inches for continuous wheat. Wheat yields the following summer were 17.1, 9.8, and 8.0 bushels per acre, respectively, for these cropping systems. These yields again emphasize the importance of st d soil moisture at seeding time on the yield of winter wheat.

D. Management Systems for Problem Soils

As reported previously, the productivity of the fine-textured soils at Newell, South Dakota, was increased by N fertilizer and/or supplemental water. This year, however, water-spreading had little influence on yields of four different grasses or the first harvest of alfalfa, because of favorable rainfall April through June. The second and third cuttings of alfalfa were increased by supplemental water. Nitrogen fertilizer (80 pounds of N per acre per year) more than doubled yields of all grasses.

Land leveling to improve water management on these shallow clay soils continues to depress productivity. Developed (leveled) pastures produced 237 and 193 pounds of yearling beef per acre from fertilized grass mixture (150 N per acre per year) and alfalfa-grass mixture, respectively. Undeveloped pastures produced 306 and 340 pounds of beef from the same forages. Fertilizers only partially restore productivity of the raw shale exposed after leveling. Corn yields on areas where the topsoil was removed during construction of terraces in Iowa were lower than those on undisturbed areas irrespective of the fertilizer treatment. Areas scalped during terrace construction responded to nitrogen and phosphorus but not to potassium or zinc.

Livestock producers are always concerned about nitrate accumulations in forages that may be damaging to livestock. On the Pierre clay soils at Newell, South Dakota, nitrate-N concentrations in irrigated and dryland oats, sorghum, and sudangrass were increased by applications of N fertilizer. The highest concentrations of NO_3-N (0.6 to 0.7 percent) were found in oat forage receiving high rates of N. These levels of NO_3 can be toxic to animals under some conditions. In several instances, irrigated oats contained more NO_3 than dryland oats, especially at later growth stages and with high N rates. Sorghum and sudangrass contained considerably less NO_3 than oats, especially at ripening stage. Highest NO_3 concentrations occurred in the lower stems of all species, suggesting that NO_3 toxicity might be a problem for livestock grazing stubble after forage harvest.

E. Nutrient Requirements of Forages

Applications of N and N + P fertilizer in 1964 through 1967 greatly increased dryland forage production, seed production, and water-use efficiency of grasses seeded in contoured rows at Sidney, Montana. Green needlegrass produced the most forage and seed in narrow rows regardless of fertilizer rate during the 4-year period. Intermediate wheatgrass produced the most forage and seed in narrow rows when fertilizer was applied, but was most productive in wide rows without fertilization. Regardless of fertility, Russian wildrye produced most forage in narrow rows and most seed in 42-inch rows for the same period. For this period, annual forage production under the most favorable row and fertilizer rate combinations has averaged 2400, 3200, and 3900 pounds per acre for green needlegrass, intermediate wheatgrass, and Russian wild ryegrass, respectively. The phosphorus content of these grasses was consistently increased by annual applications of 20 pounds P per acre in conjunction with 40 or 60 pounds N per acre, but P levels in forage were still consistently below 0.17 percent.

Removing 25, 50, and 75 percent of the vegetation in parallel miniature fallow strips from a silty range site altered the phenology and yield of some key species at Sidney, Montana. Removing 25 percent of the vegetation did not decrease total yields. Water-use efficiency was not altered by removing 25 or 50 percent of vegetation. Nitrogen fertilization (40 pounds per acre) increased forage yields and water-use efficiency. On a sandy range site, N + P fertilizer nearly doubled yields of forage. Listing and pitting stimulated some forage species sufficiently that total forage production was not reduced. Furrows created by the lister interseeder collected snow and rain, resulting in increased soil-water content.

F. Fertilizer and Cultural Practices for Wheat

Yields of winter wheat in 1967 from a deep silty clay loam at Bozeman, Montana, were greatly increased by applications of fertilizer. Check yields (no N) averaged 21.0 bushels per acre contrasted to 70.6 bushels per acre with 300 N. The 120-N rate produced 90 percent of the maximum yield without the severe lodging that occurred at higher rates. Nitrogen fertilizer increased the number of wheat heads as much as 89 percent and the kernels per head as much as 145 percent; kernel weights changed little. Nitrogen fertilizer also increased the amount of water used from 9.2 to 13.0 inches. The extra water used produced approximately 13 bushels of wheat per inch of water, a very high water-use efficiency. These results illustrate the high yield potential of winter wheat in favorable years with soil and fertilizer management practices adapted to this area. In contrast, spring wheat under almost identical conditions used nearly as much water to produce about half as much grain.

A study near Sidney, Montana, indicated after 2 years that banded N and P fertilizers increased yields of spring wheat somewhat more than surface applied fertilizer. Urea N at various rates with and without P was banded

at 4- or 8-inch depths on 12-inch spacings. Greatest production occurred with a combination of N and P, but both elements alone increased yields. Relatively large amounts of sodium bicarbonate-soluble P remained in the 4-inch and 8-inch band placements 17 months after application. Increased fertilizer rates increased water-use efficiency, and the rate of soil-water depletion in the 0- to 16-inch soil depth. As much as 15.8 p.p.m. of nitrite-N accumulated near the fertilizer bands in one instance, but no toxicity symptoms were observed.

Yields of winter wheat in the Northern Plains have always been greater than spring wheat. However, winter wheat only survives the rigorous winters about one winter out of five. Attempts are being made to enhance winter wheat survival by cultural treatments. At Mandan, North Dakota, the furrow method of seeding increased the survival and grain production of winter wheat in comparison with flat planting in 3 of the last 4 years (complete winter-kill of all plots in 1965). Supplemental water applied in the fall and spring increased yields of winter wheat in 1 of 3 years. Yields have been proportional to estimated percentages of winter survival in the field. Generally, 1 to 2 inches more snow covered wheat rows in ridged plots than in level plots.

G. Influence of Legumes on Crop Yields

Although the price of nitrogen has made it uneconomical for a farmer to use a legume in a rotation, there are soils where yields in the nonlegume rotation never attain those in the legume rotation irregardless of fertilizer treatment. For example, grain sorghum-sweet clover rotation on Austin clay soil at Temple, Texas, continues to show a significant residual effect on water intake and transmission 3 years after the rotation was discontinued. There was also a significant carryover effect of sweetclover on grain production after 3 years of continuous grain sorghum following sweetclover. Grain yield was reduced 500 pounds per acre by 2 years of grain sorghum after sweetclover and about 900 pounds per acre by 3 years of grain sorghum after sweetclover. The residual effect of sweetclover on grain sorghum production is probably caused by the mineralization of organic nitrogen from sweetclover residues.

H. Quality of Forage as Influenced by Fertilizer

Quality of Coastal bermudagrass grown in the Piedmont is being studied in relation to fertilizer and cultural practices for maximum production and optimum conservation of soil and water resources. Copper, zinc, and magnesium contents of forage were sufficiently high and silicon sufficiently low for adequate plant or animal nutrition. Manganese content of forage was at least 50 p.p.m., but increased significantly with increasing growth interval of N-K level. A negative relationship was found between soil pH and Mn content, which suggests that a soil pH of 6.5 in Cecil soils would be required to assure forage containing less than 50 p.p.m. Mn. The significance of the high Mn content in the forage depends on the reported effect of Mn/Cu ratios on vitamin-12 synthesis in the rumen and cellulose digestibility being a true relationship.

I. Nutrient Requirements of Hops

A 5-year field study dealing with fertilization of hops was conducted near Prosser, Washington. Results of the study indicate that application of phosphorus fertilizer to neutral soils is a relatively ineffective method for supplying this nutrient to established hop plants. Application of as much as 1200 pounds of P per acre over the 5-year period to soil testing low in P for most crops had no effect on plant growth, foliage color, or fruiting characteristics of the plants. The P content of the leaves was increased only slightly as a result of phosphorus fertilization. These results indicate the low phosphorus requirement of this crop and the difficulty of fertilizing established stands with phosphorus.

Publications - USDA and Cooperative Program

Cultural Practices for Steep Slopes

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NUTRITION OF ANIMALS AS AFFECTED BY SOILS AND PLANTS

(RPA 102 - Soil Structure; and Soil, Plant, Water Nutrient Relationships)

USDA and Cooperative Program

Location of Intramural Work	Scientist Man-Years FY 1968
New York	12.8
Idaho	2.2
Total	15.0

Intramural program is supplemented by extramural support representing P.L.-480 funds in 1 country, representing $8,900 U.S. dollars' equivalent.

Problems and Objectives

A number of different chemical elements move through the food chain from soils through plants and animals to people. Some of these socalled "trace elements" are present in food in very low concentrations. The elements cobalt, copper, molybdenum, zinc, manganese, and selenium are some examples of these trace elements. In recent years, it has been demonstrated that deficiencies or excesses of certain of these trace elements in the soil may have a profound effect upon animal and human health. For example, a deficiency of available selenium in some soils leads to a high incidence of "white muscle disease." In other areas, low cobalt in plants leads to cobalt deficiencies in animals. Because the food supply is the major source of the trace elements found in animal and human bodies, the reactions governing the solubility and other chemical properties of the soil become very important.

The general purpose of this research is to determine the relationships of soil properties and climatic factors on the nutritional qualities of plants as measured chemically or by feeding to test animals. Also included is the identification and characterization of soil and climatic areas where the nutritional status of animals and man is adversely affected by the quality of the food produced.

Progress - USDA and Cooperative Programs

A. Environmental Cycling of Selenium

A 7-year research program at the U.S. Plant, Soil, and Nutrition Laboratory has developed some information essential to the control of environmental levels of selenium. Selenium is required, in very small amounts, by animals, but it is toxic if present in the diet in concentrations in excess of four parts per million. This research program has helped to clarify some of the biochemical processes involved in the movement of selenium from soils-to-plants-to-animals. Some implications important to environmental quality control are as follows: (1) Areas in the United States where forage and feed crops contain different levels of selenium have been identified and shown on a U.S. map. (2) From this map, it is evident that interregional shipments of livestock feeds are a major factor in reducing selenium deficiency in the Northeastern States. (3) The addition of selenium to the soil is an effective, even though inefficient, method of prevention of selenium deficiency in animals. (4) The residual selenium left in the soil after cropping selenium-treated fields does not create a hazard of selenium toxicity. (5) Differences in selenium in the diets of residents of high- and low-selenium regions are reflected in the levels of selenium in the blood of these people, but there is no evidence of danger to humans in the United States from either selenium deficiency or toxicity. These findings will be of value to stockmen, feed companies, and Public Health officials in the evaluation of alternative methods of controlling selenium deficiencies in farm animals.

A map illustrating the selenium content of forage and hay crops in the northwestern United States has been prepared in detail at Twin Falls, Idaho, in cooperation with the Laboratory at Ithaca. The western half of Washington and Oregon and part of northern California comprise an area where forage and hay contain extremely low selenium contents. The eastern half of Washington, northern Idaho, extreme western Montana, and the northeast corner of Oregon comprise an area where forage and hay contain low selenium content. Most remaining portions of the Northwest support forage with acceptable selenium contents.

Selenium uptake by alfalfa was controlled between deficient and toxic levels for livestock in studies at Twin Falls, Idaho. Commercially available and laboratory prepared selenium compounds were injected into soil on which alfalfa was growing in the field. Materials providing adequate but nontoxic selenium contents in the alfalfa were determined. Results showed that application rates of the promising materials should not exceed 2 pounds of Se per acre.

Selenium movement through soils was studied at Twin Falls, Idaho. The selenium leached through approximately 1 foot of soil after five leachings varied from 22 to 72 percent of that applied when barium selenate and barium sulfate were applied together at a S:Se = 10. When barium selenate was applied alone, only 3 to 20 percent of the applied selenium was leached. Saturated gypsum solution leached more selenium from both sources through both soils than did water. Thus sulfur is an important factor in relation to selenium fertilization of soils.

B. Role of Manganese in Bone Formation

Chicks on a diet deficient in manganese develop an abnormality of the leg bones called "peronsis." A long-term research program at the U.S. Plant, Soil, and Nutrition Laboratory has established some of the critical features of the mode of action of manganese of this nutritional disease. The primary biochemical effect of manganese deficiency was found to be an impaired ability to synthesize chondroitin sulfate, a mucopolysaccharide normally found in cartilage and in the organic matrix of bone. Chondroitin sulfate is synthesized in the body of the chick by a stepwise process, and manganese was found to be required for the optimum activity of the enzymes that perform two specific steps in this process. Cobalt and nickel exert some stimulatory effects upon these enzymes in semipurified systems, but addition of cobalt to the diet of the chick does not enhance chondroitin sulfate synthesis in the living animal. The results of this research may help to establish the effects of varying levels of manganese contained in food plants upon the nutritional value of these plants for many species, including man.

C. Genetic Variations in Corn in Relation to Iron Nutrition

The ability of different inbred corn lines to takeup iron from soil normally producing severely chlorotic corn has been examined at the U.S. Plant, Soil, and Nutrition Laboratory. Preliminary data indicate that there are great variations in the ability of inbred corn lines to remove iron from the soil.

D. Complexing of Trace Elements in Soils

Measurements of soluble complexes in soil solution have been extended to manganese. Results showed that soil varied a great deal in manganese levels. These variations were found to be due in part to microbial mediation of the oxidation reaction. Also during the year, root measurements have been made to determine that portion of the root effective in absorbing copper and iron. Results show that the portion directly behind the tip to be the active part. These data are of value to those scientists concerned with predicting the availability of trace elements.

E. Chromium, Cadmium, and Vanadium

In recent years, there has been evidence that a deficiency of chromium may be associated with diabetics, cadmium in excessive amounts may lead to hypertension, and vanadium may inhibit the synthesis of cholesterol. Although the results from these studies are very sparse, there is sufficient evidence of the importance of these trace elements to justify additional effort with soils and plants in the future.

F. Synthesis and Metabolism of Amino Acids

The mechanism of methionine biosynthesis in plants is being investigated with the eventual aim of learning how methionine biosynthesis is controlled. Results to date suggest that the mechanisms involved are extremely complicated. Sufficient information has been obtained to indicate the need for additional effort on the problem.

G. Influence of Environmental Stress on Amino Acid Metabolism

It has been previously reported that water stress in plants leads to the accumulation of proline in plants. During the year, efforts have continued on determining the mechanisms involved. Results indicate that additional compounds from those first identified are part of this process.

H. Protein Synthesis

Studies on the nucleotide sequence of tRNA's have continued. During the year, progress was made on isolating some of the enzymes involved in protein synthesis that use tRNA as a substrate.

I. Zinc for Normal Parturition

Progress has been made during the year in understanding the specific requirement for zinc for normal births of lower animals. Additional studies will be directed toward clarification of the biochemical mechanisms involved in this requirement.

J. Trace Metals in the Gastrointestinal Tract

During the year, the effects of high levels of ascorbic acid on copper absorption have been investigated. Results show that ascorbic acid significantly depressed copper absorption only if it is put directly into the segment along with copper. In another experiment, iron was used rather than copper. Results showed a large increase in iron absorption. Future plans include a more extensive investigation of the reasons underlying the dramatic increase in iron absorption.

K. Soil and Plant Factors Related to "Grass Tetany"

The effort directed to finding a solution to the "grass tetany" problem has been intensified at the Laboratory at Ithaca. In cooperation with several field locations the studies concerned with determining the effects of organic acids on grass tetany in cattle have been given more effort. Field sampling to determine how various soil temperatures and stages of plant growth influence grass tetany has received additional attention. Growth chamber studies show that crested wheatgrass plants had sufficient concentrations of magnesium and calcium when grown at 20° C. to prevent grass tetany. However, at 10° C., the concentrations were very low. This effect was not always observed for the other grasses studied. Progress to date strongly suggests that "grass tetany" in cattle can be controlled by proper soil and water management systems.

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REMOTE SENSING FOR SPECTRAL ANALYSIS OF SOIL AND WATER CONDITIONS AND PROBLEMS

(RPA 113 - REMOTE SENSING)

USDA and Cooperative Program

Location of Intramural Work	Scientist Man-years FY 1968
Texas	4.7
Idaho	0.3
Total	5.0

Intramural program is supplemented by extramural support representing (a) 0 SMY's at State Agricultural Experiment Station, (b) 0 SMY's at other U.S. institutions and (c) P.L. 480 funds in 0 countries representing 0 U.S. dollars equivalent.

Problems and Objectives

Air and other space craft with newly-developed remote sensing detectors now make possible observation of vegetation, water and soils very rapidly over extensive areas. Interpretation of the signals received by these sensors may make possible identification of many soil, water and plant factors and conditions influencing agricultural production. Aerial cameras which photograph reflected energy in the visable and near infrared pictures of the electromagnetic spectrum have been the principle method of securing the data. New instruments now available enable the recording of emission in additional wavelengths. Recent advancements in color and infrared photography, thermal infrared, microwave and low frequency radar sensing, and other technological developments show excellent promise for detection and interpretation of plant, soil and water phenomena. Ground truth information for accurate readout of recordings and means for automatic image scanning and readout are currently limiting fuel and effective use of this new tool for crop and soil survey, moisture stress, nutrient deficiency, salinity, irrigation scheduling and other soil-water-plant problem identification and measurement.

Major objectives of the research are to develop procedures for accurate interpretation of remote sensing recordings by:

1. Determining thermal and reflectance characteristics of soils.
2. Relating spectral reflectance to induced leaf changes by salinity, moisture stress, and plant nutrients.
3. Instrument development and field testing.
4. Study of electromagnetic scattering and reflectance by use of a simulated plant.
5. Identifying multiband signatures of various plants.

Progress - USDA and Cooperative Programs

A. Thermal and reflectance characteristics of soils

1. Qualitative soil moisture conditions in bare soils were detected from airborne thermal scanner imagery at Weslaco, Texas. High heat capacity of water results in a more uniform thermal equilibrium in moist soils than in dry soils. Imagery flown at 0530 hours was best for showing soil moisture. Negative heat transfer to the soil surface occurs after sundown. As a result, 1830 hours imagery shows surface soil temperature contracts that are indicative of subsurface conditions.

B. Moisture stress, nutrient, and salinity effects on leaf reflectance

1. Research at Weslaco, Texas, showed that reflectance from cotton plants at certain wavelengths may be used to predict the moisture status of plants and possibly the need for irrigation. Reflectance at 1.45 and 1.93 microns was significantly related to total moisture content and relative turgidity of leaves.

2. Leaf reflecting power in the visible region of the spectrum (0.4 to 0.7 micron) is associated with the concentration of pigments within the plant cells. A highly significant inverse relation between reflectance and the chlorophyll and carotenoid content of leaves from several plant species was found in studies at Weslaco, Texas. Because of differences in leaf morphology, leaves from different plant species having the same pigment content do not have the same reflective power.

3. The effects of the matric and osmotic components of total soil water suction in relation to several factors for salinity-affected cotton were evaluated at Weslaco, Texas. Leaf temperature increased with an increase in the total soil water suction. Since total soil moisture was generally adequate during the season, the osmotic suction accounted for nearly all the variation in leaf relative turgidity and in leaf temperatures.

C. Instrument development and field testing

1. The thermal behavior of 40 plant and soil sites was studied from thermal imagery obtained with an airborne scanner at Weslaco, Texas. Equivalent black-body temperature in thinned grain sorghum (midday flight) was a linear function of leaf area index. Freshly irrigated crops ranging in percent ground cover from 37 percent to 70 percent were up to 20° C. cooler under midday conditions than nonirrigated portions of the same fields.

2. Color optical density decreased as altitudes increased progressively from 2,000 to 12,000 feet for all films studies at Weslaco, Texas. A decrease in optical density means an increase in film transmittance.

3. A small, portable, battery-powered field reflectometer, which utilized an integrating sphere, was developed for measuring reflectance from soils and intact leaves at Twin Falls, Idaho. Its light source was a flashlight bulb; its wavelength selection within the range of 0.4μ to 1.1μ was achieved with interference filters. Comparison with laboratory instruments was favorable.

D. Electromagnetic scatter and reflectance

1. The Kubelka-Munk (K-M) theory, a two-parameter representation of diffuse light transmission, has been applied successfully at Weslaco, Texas, to explain the reflectance and transmittance phenomena of stacked leaves. The procedures are sufficiently general to apply to an actual plant canopy. The K-M theory has great flexibility to specify the interaction of light with a plant canopy.

Publications - USDA and Cooperative Program

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